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Technological Innovation, Corporate R&D Alliances and Organizational Learning

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PREFACE

The rapidly changing global economy can be viewed from the shores of merging streams of geopolitical events, management trends and new ideas. Among these are recent applications of the science of complexity to social and business questions; corporate experimentation with a variety of new management concepts including so-called "organizational learning," and the shift from strictly competitive tactics to mixed cooperative and competitive strategies using multiple alliances for competition in global markets. These streams coincide with the end of the cold war, which has seen the transformation of national security policies based on relative military might to those designed to maintain, or regain, global technological and economic supremacy.

In the domain of technology and innovation policies, these trends are poised squarely on the horns of a fundamental dilemma: "How can a nation achieve or maintain relative competitive strength, much less leadership, if it opens its boundaries through cooperative research alliances?" Put in other terms, "since sharing and cooperating imply giving away knowledge in order to develop new knowledge, don't the industrialized countries risk losing all relative advantage by allowing their private sector technology-based firms to form cooperative research ventures?"

This dilemma helps explain the split character of the evolving U.S. science and technology policy. While the current Administration is advocating increased domestic cooperation among firms, universities and the government, and even suggesting international cooperation between governments on large scale science projects, substantial roadblocks have often been erected to impede corporate cooperation with international firms. Moreover, the Anti-Trust Division of the Justice Department has recently launched a new effort to scrutinize high-tech alliances and mergers. The Division is particularly concerned about joint research and development efforts.

The same dilemma is present at the corporate level. In today's global and rapidly changing economy, technology-based firms must

carefully consider the tradeoff between the opportunities and hazards of cooperative research alliances. How the dilemma is resolved at this level may depend in large measure on the degree to which corporate executives have engaged in cooperative ventures in the past. It may also depend on their relative degree of comfort with organizational learning strategies.[1]

How the dilemma of relative gains is resolved at the policy level may also depend on the perceptions of policymakers concerning the benefits and risks of corporate level cooperative R&D. These must be weighed against the perceived risk of shifts in relative national advantage and the potential for corporate collusion. Economists have noted that the collusion threat (the regulatory domain of antitrust laws) is much diminished in the global environment of relatively free trade. Furthermore, the concern about relative gains, the focus of U.S. trade laws and negotiations, may have much less relevance in a world of very cooperative, yet intensely competitive, and constantly innovating firms.

The research reported here was undertaken to determine whether and to what extent innovation and financial benefits result from corporate participation in cooperative R&D alliances, and how that participation is shaped by executive attitudes toward the learning opportunities and opportunistic threats that alliances pose. The purpose of the inquiry is to inform policymakers about the potential impact of alternative policies that affect corporate behavior and innovation performance, as well as to inform corporate R&D executives of any measurable benefits of cooperative R&D activity.

The results show positive innovation and economic benefits from alliance participation, particularly international R&D alliances. To

[1] Organizational learning encompasses both the design and operation of the internal organization and its external relationships with other innovating firms and customers. Internally, the degree to which the firm is organized as a traditional top-down hierarchy or as a more horizontal, participatory network may be significant. The number of external innovation partners play an important role in the learning capability of firms. Moreover, the executives' attitudes toward alliance opportunities and the quality of partner relationships and communication may affect the information acquisition from partner firms.

the extent that cooperating firms generally benefit from alliance participation, the major policy implication is that government incentives should be structured to permit or even facilitate, rather than discourage, such alliances. Indeed, international R&D alliances should be encouraged, and "transnational" trade and antitrust policies[2] adopted. Increased cooperative alliances will not only increase the innovative learning capabilities of private-sector firms, but open new markets, and therefore new consumer and customer sources of innovation. Antitrust efforts designed to enforce the General Agreement on Tariffs and Trade should not restrict cooperative alliances unless a comprehensive dynamic analysis of the threats of collusion indicates that their drawbacks clearly outweigh the innovation benefits of cooperation. The analysis of this research suggests that such a showing may be difficult to make.

This dissertation research was completed in partial fulfillment of the requirements of the RAND Graduate School for the degree of doctor of Philosophy in policy analysis.

[2] As opposed to neomercantilist policies that seek to enhance national "competitiveness" without consideration of the benefits of cooperation. These policies will be described in more detail in this report.

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SUMMARY

Science and technology policy is viewed by many as a key policy domain affecting economic growth, and therefore prosperity and the quality of life. (Griliches, 1984; Grossman & Helpman, 1994; Rosenberg, 1972). Consequently, the academic field of technology policy is rich with prior research and multiple threads of economic thought and policy analysis.

Because of the vastness of the literature and prior work in this area, it would be foolhardy to attempt a general synthesis of prior work and a full comparative history of national technology policies, and presumptuous to recommend comprehensive prescriptions for improving technology policies across the board, in the U.S. or elsewhere. Nevertheless, significant developments in innovation theory and practice have occurred in the past few years. These trends portend a new model of innovation and have important implications for national technology policies.

Specifically, a new way of looking at the innovation process as a fully integrated learning process among a network of participants, including customers, seems to be emerging. In part, this reflects the growing number of research and development cooperative alliances between and among firms, and the increasing globalization of industry and research. Indeed, many firms are behaving as if cooperative alliances increase their ability to innovate and compete in the marketplace. If that is the case, one would expect patent output and profitability would be correlated with alliance experience.

National policies have begun to reflect the commercial alliance trends. National policies in Japan and Europe, and more recently the United States, have encouraged alliances within the particular country or trading bloc (in the case of the European Commission). These policies have generally been motivated to make the relevant national sector more competitive relative to firms of other countries. Despite these policy trends, there remains a great deal of uncertainty about the value of alliances, especially those with overseas firms. This leads to

substantial official skepticism, policy impediments, and increasing threats of anti-trust prosecution that block or discourage firms from cooperating with international partners as much as they might otherwise.

Some have written persuasively that the entire worldwide system of research and development, production and distribution is becoming integrated or globalized. (Howells, 1990; Merrifield, 1992; Pearce, 1989). Others have pointed out that significant local, regional and national innovative and production resources, skills and synergies persist and remain impervious to the globalization trend. (Dosi, Zysman, & Tyson, 1990; Niosi & Bellon, 1994, 193). Some firms embrace the opportunities to form research and development alliances, domestic and international; others shun alliances. Some government policies facilitate such cooperative commerce domestically,[3] many others impede, or threaten to impede, the trend as it relates to international alliances.[4] Even though pressures will continue to grow for cooperative international research policies, the "virulence of nationalism"[5] remains strong. Indeed, the intertwining policies and trends have resulted in an extremely complex policy landscape. (Niosi & Bellon, 1994, 195).

In the midst of this ever more apparent complexity, this research was designed to test whether firms gain innovative and profitability benefits by engaging in research and development cooperation. The issue of whether national policy should encourage or restrict such firm-based openness is not directly tested. But policy implications can be drawn from the analyzed data.

In the project, I focused on three high technology intensive sectors: aerospace, automotive and semiconductors. The research was designed to test whether and to what extent firm innovative and profit

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[3] Such as the Advanced Technology Program (ATP), and the government sponsored consortia such as SEMATECH and the Partnership for a New Generation Vehicle (PNGV).

[4] These include restrictions on foreign participation in SEMATECH and the PNGV consortia, and many amendments proposed in the last session of Congress to the National Competitiveness Act which would bar overseas use of technologies developed under grant programs sponsored by the Act.

[5] As one author recently wrote, "...the opportunities and needs for international scientific cooperation will grow as interdependence advances. However, the virulence of nationalism is more characteristic than the growth of international federalism." (Skolnikoff, 1993).

performance is positively related to, or affected by, cooperative research and development activity.

Specifically, I designed the research to test five interrelated hypotheses. These hypotheses are the following:

1. The more firms cooperate in research and development projects, the more innovative and profitable they will be.

2. The better that firms are organized for external technological learning (more external alliances, better external communication flows and favorable executive attitudes toward alliance learning opportunities) and internal information processing (reduced hierarchy, use of cross functional R&D teams, etc.), the more innovative and profitable the firms will be.

3. The more executives focus on the learning opportunities presented by alliances, rather than the possible threats of partner opportunism, the more the firms will form alliances and succeed with their ongoing alliances.

4. The better the perceived communication quality from alliance partners, the more firms will form alliances, and perceive greater success with ongoing alliances and fewer transaction costs.

5. The more experience firms have with cooperative alliances, the more the firms will form alliances and succeed with their ongoing alliances

I tested the first hypothesis with a broad set of alliance, patent and financial data. The patent data provide a reasonable proxy measure of firms' innovativeness. The financial data provide profitability information.

RAND obtained alliance data from MERIT, the Maastricht Economic Research Institute on Innovation and Technology at the University of Limberg, Netherlands, as well as from the Securities Data Corporation (SDC). The MERIT database is known as CATI, the Cooperative Agreements and Technology Indicators database. It covers the years 1969 to 1989, but coverage is strongest beginning in 1979. The SDC data include alliances from 1985 through 1992. Its coverage during the first three years is limited, but very complete from 1989 through 1992. These data

were combined with five-year (1988-1992) patent data summaries from CHI Research, Inc.

The alliance data indicate a remarkable increase in R&D alliance activity over the last decade and a half. Table S.1 indicates the growth in the number of R&D and total alliances from 1979 though 1992. Note that the number of alliances formed in these sectors during the last four years (1989-1992) is almost seven times (680%) the number of alliances formed in the first four years of the data (1979-1982).

Table S.1

Aggregate Number of Alliances Established in the Semiconductor, Automotive and Aerospace Sectors 1979-1992

Year	R&D Alliances	Non-R&D Alliances	Total Number of Alliances
Before 79	67	228	295
1979	25	46	71
1980	47	71	118
1981	41	65	106
1982	36	63	99
1983	40	58	98
1984	88	82	170
1985	68	153	221
1986	95	224	319
1987	66	228	294
1988	106	278	384
1989	97	281	378
1990	161	547	708
1991	358	695	1053
1992	399	561	960
Total	1694	3580	5274

NOTE: The data include alliances from the CATI and SDC databases. Alliances in both databases have been eliminated from the SDC data.

To test the impact of organizational learning factors on innovation and profitability (for Hypotheses 2-5), I developed and tested a 21-question questionnaire and sent it to research and development vice presidents of 505 firms in the three high-tech sectors. The 75 responses provide additional data on the experiences, attitudes and

perceptions of R&D executives relating to alliances. Data were also obtained on the external and internal communication quality, organizational learning practices, degree of internal integration and profit experience of the responding firms.

My analysis of the pre-existing alliance, patent and financial data leads to the following conclusions:

- Alliance behavior is a good predictor of patent performance. Table S.2 shows the patent regression coefficient for the total number of R&D agreements.[6] The regression is for the total data set and indicates that about 14 additional patents are correlated with each additional R&D agreement.

Table S.2

Patent Regression Coefficient for All Agreements from Table 5.8

Dependent Variable: Sector Patents	
Independent Variable	
Total R&D Agreements	14.1****

NOTE: **** indicates significance at the p<.0001 level.[7] The actual regression is in logs. The value shown is for the unit marginal. The regression is controlled for average 3-year sales.

- International alliances, as shown in Table S.3,[8] have a greater impact on patent performance than do domestic alliances.

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[6] The regression is based on the following equation:

$$\text{Sector patents} = a_o + b_1 \text{Total R\&D Agreements} + b_2 \text{Average 3year sales} + e_r$$

[7] p<.0001 means the probability is less than .0001 that the predictor variable has zero impact on, or correlation with, the outcome variable.

[8] This regression is based on the same basic model as Table S.2 with the Total R&D Agreements term disaggregated into domestic, trading-bloc only and cross-trading bloc terms.

European Union alliances have no discernible impact. Each international alliance is correlated with an increase of about 24 patents, while each domestic alliance is correlated with an increase of about 12 patents. European Union only alliances have no significant correlation.

Table S.3

Patent Regression Coefficients for Domestic, European Union and International Agreements from Table 5.8

Dependent Variable:	Sector Patents
Independent variables	
Domestic agreements	11.6***
EU only agreements	-1.95[a]
International agreements	23.5****

NOTE: **** indicates significance at the p<.0001 level, *** is significance at the p<.001 level. The actual regression is in logs. The values shown are for the unit marginals. The regression is controlled for average 3-year sales.
[a] p value is .85.

- Profit performance is positively correlated with alliance experience. But since the relationship is more distant in time and is subject to multiple intervening factors, the correlations are weaker than the correlation between patent performance and research and development alliances. Table S.4 summarizes three separate profitability regressions.[9] As seen

$$\text{Sector patents} = a_o + b_{11}\text{Domestic RD Agreements} + b_{12}\text{Trading - bloc Agreements} + b_{13}\text{Cross - trading bloc Agreements} + b_2\text{Average 3 - year Sales} + e_r$$

[9] These regression are based on the following three models:
(1)

$$\text{Profits} = a_o + b_1\text{Total R\&D Agreements} + b_2\text{Average 3year Sales} + e_r$$

in this table, the average three-year (1990-1992) net income of U.S. firms (regression 2) is influenced positively by alliance behavior. This regression includes a control for average R&D spending that is not available for the all firms' regression (regression 1), or for the regression on the three distinct types of alliance agreements (regression 3). In the third regression shown, domestic alliances and alliances within the European Union have significant negative impacts. But truly international alliances, those that cross trading blocs, have a strong and significant positive influence on profitability.

Table S.4

Profit Regression Coefficients for Total, Domestic, EU and International Agreements from Table 5.13

Dependent Variable:		Average 3-Year Profits $M
Independent Variables		
Regression	(#)	
Total R&D agreements. All firms.	(1)	.56[a]
Total R&D agreements. US firms-only with correction for R&D expenses	(2)	12.3****
Domestic Agreements	(3)	-8.1***
EU Only Agreements	(3)	-56.9****
International Agreements	(3)	11.4****

NOTE: **** indicates significance at the p<.0001 level, *** is significance at the p<.001 level. The values shown are for the unit marginals. All regressions are controlled for average 3-year sales.
[a]p value is .58.

In addition to the analysis of existing alliance and patent databases, the research analyzed alliance experience data obtained

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$$\text{Profits} = a_o + b_1\text{Total R\&D Agreements} + b_2\text{Average 3year Sales} + b_3\text{Average 5 year R\&D Spending} + e_r \quad (2)$$

$$\text{Profits} = a_o + b_{11}\text{Domestic R\&D Agreements} + b_{12}\text{Trading-bloc Agreements} + b_{13}\text{Cross-trading bloc Agreements} + b_2\text{Avg 3year Sales} + e_r \quad (3)$$

directly from 74 aerospace, semiconductor and automotive firms. My analysis of the combined survey and pre-existing data leads to the following observations and conclusions:

- As indicated on Table S.5,[10] the patent output of responding firms is increased in a statistically significant manner by higher numbers of linkages (alliances), improved quality of external communication flows, positive executive attitudes toward the mutual learning opportunities of alliances, and firm design favoring organizational learning. Internal information flow quality has a non-significant positive correlation with patent production. But traditional top-down hierarchies have a significant negative effect on patent production.
- In contrast, profitability is affected in a significant positive manner only by increased numbers of alliances. External information quality, traditional hierarchies, and R&D spending have positive but non-significant correlations with profitability. A mutual learning focus has a negative, but non-significant correlation.

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[10] The regressions of this table are based on the following models:

(1)

$$\begin{aligned}\ln(\text{SecPATS}) = {} & a_o + b_1\text{MutualLearnFocus} + b_2\text{OpportunismFocus} \\ & + b_3\text{EconomicsFocus} + b_4\ln(\text{TotalRDAgreements}) + b_5\ln(\text{Avg3yearSales}) \\ & + b_6\text{ExternalInfoFlowQuality} + b_7\text{OrganizationLearnIndex} \\ & + b_8\text{TopDownIndex} + b_9\text{InternalInfoFlowQuality} + b_{10}\text{QFD} \\ & + b_{11}\ln(\text{3yearAvgR\&DBudget}) + e_r\end{aligned}$$

(2)

$$\begin{aligned}\text{Profits} = {} & a_o + b_1\text{MutualLearnFocus} + b_2\text{OpportunismFocus} \\ & + b_3\text{EconomicsFocus} + b_4\text{TotalRDAgreements} + b_5\text{Avg3yearSales} \\ & + b_6\text{ExternalInfoFlowQuality} + b_7\text{OrganizationLearnIndex} \\ & + b_8\text{TopDownIndex} + b_9\text{InternalInfoFlowQuality} + b_{10}\text{QFD} \\ & + b_{11}\text{3yearAvgR\&DBudget} + e_r\end{aligned}$$

Table S.5

Patent and Profits Regression Coefficients for Linkages and the Quality of Information Flows - from Table 6.5

Dependent Variables	Total Patents	3-Year Profits
Independent variables		
Mutual learning focus	440.4*	-292.5$^{p=.29}$
External R&D linkages-research agreements	17.5****	8.07**
3-year average annual Sales	NS	.0178****
External information flow quality	174.1*	104.9$^{p=.37}$
Internal information flow quality	134.9$^{p=.16}$	NS
Organizational learning index	362.0**	NS
Top down index	-337.8**	166.7$^{p=.34}$
3-year average annual R&D spending	.031$^{p=.38}$	.080$^{p=.12}$

NOTE: **** indicates significance at the p<.0001 level, *** is significance at the p<.001 level, ** at the p<.05 level and * at the p<.1 level. NS (No significance) means p>.5. The patent regression is in logs. The values shown are for the unit marginals. The regressions are controlled for average 3-year sales.

The regressions summarized in Table S.6 are used to test Hypothesis 3, 4 and 5.[11] The impact of external organizational learning factors (attitude, communication and alliance linkages) on the executive perceptions of success, frequency of problems, and on the rate of forming new alliances is shown by the regressions.

Executive attitudes toward the formation of alliances include a focus on the mutual learning opportunities that alliances provide,

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[11] These regressions are based on the following models.

(1)

$$\begin{aligned}\text{Success Index} = \; & a_o + b_1\text{MutualLearnFocus} + b_2\text{Opportunism Focus} \\ & + b_3\text{EconomicFocus} + b_4\text{External} - \text{InfoQuality} \\ & + b_5\text{TotalR\&DAgreements} + e_r\end{aligned}$$

(2)

$$\begin{aligned}\text{ProblemFrequency} = \; & a_o + b_1\text{MutualLearnFocus} + b_2\text{Opportunism Focus} \\ & + b_3\text{EconomicFocus} + b_4\text{External} - \text{InfoQuality} \\ & + b_5\text{TotalR\&DAgreements} + e_r\end{aligned}$$

(3)

$$\begin{aligned}\ln(\text{NewR\&D Agreements}) = \; & a_o + b_1\text{MutualLearnFocus} + b_2\text{Opportunism Focus} \\ & + b_3\text{EconomicFocus} + b_4\text{External} - \text{InfoQuality} \\ & + b_5\ln(\text{CATIR\&DAgreements}) + e_r\end{aligned}$$

concern for the threats of opportunistic partner behavior that they present, and the relative perceived importance of traditional economic justifications for alliance participation.

These economic factors include risk sharing, cost reduction, accelerating the return on investment, and the creation of efficiencies through economies of scale. Mutual learning factors, on the other hand, include the ability or opportunity to commercialize new technologies faster, learn new technologies and processes, increase the connection with target markets and consumers, enhance firm-wide innovation and manufacturing/marketing expertise, share in the financial benefits of new markets and technologies, and develop high levels of trust with potential partners. Opportunistic threats include loss of key knowledge, or the fruits of research to partners, the costs of monitoring partner performance and the losses if the partner fails to perform or takes advantage of the alliance for competitive reasons.

Analysis of these data shows the following:

- Perceptions of success are correlated with a mutual learning focus and the total number of R&D agreements in which a firm has participated. But the strongest effect is the perceived quality of communication from alliance partners.
- In contrast, the perceptions of problems are negatively correlated with the quality of partner communication and total agreements. The strongest predictor of problem frequency is the degree to which executives focus on the threats of opportunistic partner behavior.
- Finally, the formation of new alliances is positively and significantly correlated with a mutual learning focus and the number of prior R&D agreements, and negatively and significantly correlated with an opportunism focus.

Together, these findings provide varying degrees of support for Hypotheses 3, 4 and 5.

Table S.6

Success, Problems, Patents and Profits Regressions Coefficients on Mutual Learning Focus, Opportunism Focus and Economic Focus Indexes from Table 6.9

Dependent Variables	Success Perception Index (0-1)	Problem Frequency Index (0-1)	New R&D Agreements
Independent variables			
Mutual learning focus	.462*	NS	2.46**
Opportunism focus	NS	.396***	-1.60**
Economic focus	NS	NS	NS
External communication quality	.476****	$-.100^{p=.12}$	NS
Total R&D agreements	$.003^{p=.11}$	$-.001^{p=.27}$	NA
CATI R&D agreements (old)	NA	NA	.988****

NOTE: The sign indicates the sign of the coefficient. *** indicates significance at the p<.001 level, ** is significance at the p<.05 level, * is significance at the p<.10 level. NS (No Significance) means p≥.5.

For the empirical database analysis, causality from alliances to patent production has been shown, but in magnitude only. In other words, the level of patent production influences the establishment of alliances in a positive and significant manner, but the relative magnitude of this effect is much smaller than the influence of alliances on patent output. Causality from alliances to profits is much clearer. Indeed, the effect of increased profitability on the formation of alliances is negative.[12]

In general, it appears that alliance participation enhances the scope of firm organizational learning capacities, and innovation output. This implies that national policies should not intentionally obstruct or discourage commercial cooperative R&D alliances. And international R&D

[12] Possible explanations for this finding include the following: (1) firms with higher profits due to monopolies of specific technologies or products may have little incentive to form cooperative ventures, (2) firms with losses may have greater incentive to cooperate in order to enhance their technological learning and return to profitability, or (3) there may be a point of diminishing returns from alliances that is a function of market position and alliance experience. Profitable firms may be better at determining that point; and less successful firms may engage in too many alliances. However, my sense is that explanations (1) and (2) are probably more accurate.

alliance activity should receive the highest policy deference, even encouragement.

The following conclusions are implied by the research findings. Anti-trust policies and enforcement efforts against cooperative research alliances should be restrained unless a clear showing can be made that the threat of collusion (measured dynamically with all international players included in the analysis) outweighs the benefits of cooperation. Likewise, to the extent cooperative alliances are viewed as legitimate corporate strategies, trade policies that punish foreign cooperating firms in order to protect domestic industries should be revised. Finally, where research consortia are formed to develop new technologies or standards, international firms should not be automatically barred from participation. In fact, all else being equal, foreign firms should have equal opportunity to join such consortia and contribute.

While not directly tested by this research, the microeconomic model of cooperative research shown in Appendix C indicates that cooperative research generates effective increases in basic research knowledge. This implies that the increasing numbers of research alliances observed by this research may reduce the effective need for substantial government R&D subsidies.

At the firm level, the implications of this research are complex. At this level, the best alliance strategy depends on a variety of sector and competitive factors, which can be understood only with detailed sector and industry studies, coupled with intimate knowledge of the firm's strategic positioning, knowledge assets, product mix, and short and long-term directions.

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GLOSSARY AND SYMBOLS

AllDomRD	All Domestic R&D Agreements
AllTBORD	All Trading-Bloc-Only R&D Agreements
AllXTBRD	All Cross-Trading-bloc R&D Agreements
ANOVA	Analysis of Variance
ATP	Advanced Technology Program
AV3YRSALES	Average 3-Year Sales (1990-1992)
AVNI	Average Net Income (Profits) (1990-1992)
AVGRD8892	Average 5 Year R&D Expenses 1988-1992
CATI	Cooperative Agreements and Technology Indicators database
CATIRDAG	Number of CATI R&D Agreements
CATIRDPTX	Number of CATI R&D Agreement Partners
CATISECRD	CATI Firm sector R&D Agreements
CEO	Chief Executive Officer
CII	Cumulative Impact Index
DARPA	Defense Advanced Research Project Agency
E_r	Residual Model Error Term in Regressions
E.U.	European Union
GATT	General Agreement on Tariffs and Trade
INFLO-EXT	Quality of External Information Flows
INFLO-INT	Quality of Internal Information Flows
IPC	International Patent Classification
JDA	Joint Development Agreements
JRP	Joint Research Pacts
LEARNINDEX	Organizational Learning Index
LISREL	Linear Structural Relations Model
LNAllDOMRD	Log All Domestic R&D Agreements (CATI and SDC)
LNAllTBORD	Log All Trading-Bloc-Only R&D Agreements
LNAllXTBRD	Log All Cross-Trading-Bloc R&D Agreements
LNAV3YRSALES	Log Average 3-Year Sales

LNAVRD8892	Log Average 5-Year R&D expenses
LNCSECRD	Log of CATI sector R&D agreements
LNPTRDEMP	Log Patents per 1000 R&D Employees
LNSALLRD	Log SDC All R&D agreements
LNSDomRD	Log SDC Domestic R&D Agreements
LNSECPATS	Log Sector Patents
LNSTBORD	Log SDC Trading-Bloc-Only R&D agreements
LNSXTBRD	Log SDC Cross-Trading-Bloc R&D Agreements
LNTSSECTOR	Log Technical Strength for the Firm-Sector
LPTRDEMP	Log Patents per 1000 R&D Employees
MCC	Microelectronics and Computer Corporation
MERIT	Maastricht Economic Research Institute on Innovation and Technology
MLF	Mutual Learning Focus
NAFTA	North American Free Trade Agreement
OECD	Organization of Economic Cooperation and Development
PATS/KRDEMP	Patents per 1000 R&D Employees
PNGV	Partnership for a New Generation Vehicle
PROFITS	Average 3-Year Profits (1990-1992)
QFD	Quality Functional Deployment (a Measure of Internal R&D Integration)
QFD INDEX	Same as QFD
RC	Research Corporations
R&D	Research and Development
RDC	Research and Development Contract
RJV	Research Joint Venture
SDC	Securities Data Corporation database
SDCALLRD	All SDC R&D Agreements
SEC	Security and Exchange Commission
SECPATS	Sector Patents
SIC	Standard Industrial Classification

TCT	**Technical Cycle Time**
3YRAVGRD	**3-Year Average R&D Spending**
TOTRDAG	**Total R&D Agreements (Includes CATI and SDC Agreements)**
TSSECTOR	**Technical Strength in the Sector**

1. INTRODUCTION

GENERAL

This dissertation was designed to test whether and to what extent cooperative research and development ventures among private firms enhance the innovative and profit making capability of participating firms. To test these correlations, substantial alliance, patent and financial data were acquired and linked for firms in the aerospace, automotive and semiconductor industries. In addition, a survey was sent to firms in these sectors. Together these data provide a comprehensive and unique look at the effect of research and development alliances on firm innovative and economic performance.

The crucial question for policymakers is what such firm-based cooperative experience means for national technology policy.

This is a particularly important policy inquiry, because U.S. technology policy is changing rapidly. For the past two years the Administration has advocated extensive government involvement in technology development. With the recent Republican victories in the Congress, many of the Administration programs may be closely scrutinized or abandoned.

In recent years, a variety of policy papers have advocated a wide range of targeted interventions and government actions to enhance the development of U.S. technology under conditions of market failure, insufficient appropriability or national security. (Alic, Branscomb, Brooks, Carter, & Epstein, 1992; Brown, Mowery, & Perry, 1992; Costello & Ernst, 1992; Inman, Augustine, Branscomb, & Perry, 1991; Schmitt & Bement, 1992; Staff, 1992; Young, Gray, & Inman, 1988). The current Administration has been clearly committed to substantially increasing government involvement in technology development with its Advanced Technology Program, Technology Reinvestment Project, Manufacturing Centers of Excellence and conversion of the Defense Advanced Research Projects Agency (DARPA) into the Advanced Research Projects Agency. Yet at the same time, the Administration is substantially increasing its

anti-trust enforcement capabilities and efforts, specifically targeting high-tech R&D cooperation for close scrutiny. (Jenks, 1994; Jenks, 1995).

Thus, not only does it appear that there is a "major contradiction within Clinton's high tech policy" (Jenks, 1995), with the changes in Congress the active financial involvement of the Administration in technology development may be in jeopardy. So the overarching policy issue for this research is how much should the government be involved in supporting basic research and technology development. More directly tied to this research is the anti-trust question: To what degree should government tolerate or encourage R&D cooperation among firms?

Related to both of these is the issue that arises when the government attempts to stimulate innovation by sponsoring research consortia, such as SEMATECH and the Partnership for a New Generation of Vehicles. In such situations, the government has traditionally acted to preclude any foreign company participation in the consortia, either directly or indirectly. Thus, another policy issue is whether such exclusionary policies affect the innovation potential of such consortia.

Rather than attempting to fully inform these policy issues, this research investigates the upside of cooperative research arrangements. Specifically, it examines the innovation and financial benefits accruing to firms engaged in cooperative alliances. It also explores whether the external learning behavior of firms, consisting of alliance connections, communication flows and executive attitudes toward alliances, have an impact on patent production, profitability, the propensity to form alliances, and the perceptions of success and problems that arise in such ventures. Finally, the research tests whether alliance experience makes a difference in the frequency and success of alliance activities.

The strong positive correlation found in the research between innovations, as measured by a patent count proxy, and alliances, particularly international alliances, suggests the wisdom of substantial caution in targeting cooperative research alliances for anti-trust enforcement,[13] or for exclusion from government sponsored consortia.

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[13] The weak, and in some cases negative, correlation between profitability and alliances also supports this conclusion.

Finally, the sector differences among the alliance correlations suggest that the benefits and hazards of cooperation vary from industry to industry. Thus, the research supports the view that anti-trust enforcement should be informed by the particular impact of alliances within each industry under review.

From the corporate perspective, the results of the research suggest that substantial benefits accrue to firms engaged in research alliances. However, outcomes vary substantially depending on the sector and the domestic or international scope of alliances. Moreover, favorable executive attitudes toward alliances, effective communication flows between partners and cooperative experience enhance the probability of alliance success.

OUTLINE OF THIS RESEARCH REPORT

Section 2 summarizes the corporate movement toward integrated research and development, and the increasing level of research alliances. It also describes in more detail the primary policy and theoretical dilemmas that affect these developments and how this research addresses these issues.

Section 3 discusses the research plan and hypotheses as they relate to the prior theoretical work and empirical research. Section 4 describes the methods I used to obtain and organize the necessary data to test the hypotheses, including the structure and content of five analysis databases. Extensive analysis of Hypothesis 1 using the alliance, patent and finance data is treated in Section 5. In Section 6, I analyze the survey data to test Hypotheses 2, 3, 4 and 5. Finally, in Section 7, I explain the conclusions inferable from the empirical data, as well as the policy implications which are supported, or suggested, by the research findings.

2. BACKGROUND FOR THIS RESEARCH

RESEARCH ALLIANCE INTENSITY AND GROWTH

Corporate research alliances are proliferating. The increase in alliance activity has been reported by various researchers. (Hagedoorn & Schakenraad, 1991; Hagedoorn & Schakenraad, 1992; Haklisch, 1986; Jarillo & Stevenson, 1991; Mytelka, 1990; Pury, 1994; Rycroft & Kash, 1994; Schein, 1993; Senge, 1990; Tent, 1990). Data collected for this research are somewhat more extensive than previously reported and show clearly the increasing cooperative alliance trend. Not only are annual alliance start-ups higher over the last three years involved in this research (1990-1992), the cumulative number of existing alliances appears to be increasing at constant rates in the three sectors explored in this research. Figure 2.1 illustrates the total rate of these cumulative increases.

Note that Figure 2.1 is derived from the total population of R&D alliances for the three research sectors (aerospace, automotive, semiconductors) from both the CATI and SDC databases. Table 2.1 provides the numerical totals for each of the three sectors. The dramatic growth rate shown for the years 1989 to 1992 is similar to that reported by Pekar and Allio who estimate that over 20,000 U.S. alliances were forged between 1988 to 1992, whereas only 5100 were created from 1980 to 1987.[14] (Pekar Jr. & Allio, 1994).

Moreover, according to data compiled and interviews conducted by *Business Week* in 1994, "the hottest trend [in R&D] is collaboration." It is "sweeping every field, in fact, from autos to aircraft to biotechnology." (BWStaff, 1994).

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[14] These numbers, however, are merely estimates derived from responses to a questionnaire sent to 750 executives, of which 14% responded. However, according to one of the authors, his consulting experience with Booze, Hamilton and Allen, and the rapid growth of interest in this field, leads him to believe the numbers, while soft, are very conservative. He is convinced the real number is substantially higher. (Pekar, 1994)

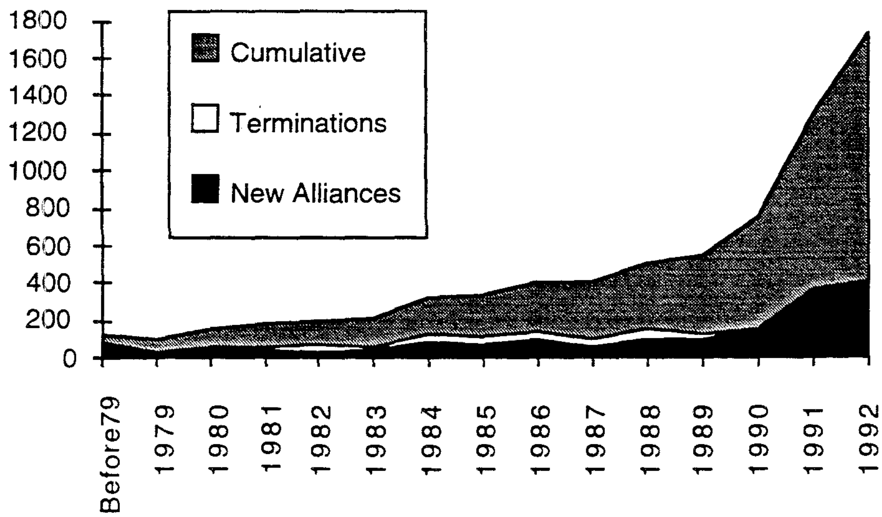

Figure 2.1—Cumulative R&D Alliances in the Semiconductor, Automotive and Aerospace Sectors

Despite these trends, not all firms and executives are embracing the alliance movement. Some technology firms have no research alliances at all. For example, AMP, Inc., an innovative semiconductor firm, has no research alliances in the CATI and SDC data. And acceptance and experience varies across countries. For example, a recent survey by Booz-Allen, the *Wall Street Journal,* and *Nihon Keizai Shimbun* (a Japanese business periodical), found that 74 percent of Japanese CEOs think alliances are effective, while only 4 percent think they are dangerous. In the U.S. 17 percent of the CEOs thought alliances effective, 31 percent consider them dangerous. (Harbison & Pekar Jr., 1993).

Nevertheless, the number of alliances continues to grow. The figures shown in Table 2.1 represent just the research alliances. The total number of alliances may be about three times these numbers.[15]

[15] See Table 4.4 below.

Nevertheless, the number of alliances continues to grow. The figures shown in Table 2.1 represent just the research alliances. The total number of alliances may be about three times these numbers.[15]

Table 2.1

Research and Development Alliances Established in the Semiconductor, Automotive and Aerospace Sectors

Year	Semiconductor	Automotive	Aerospace
<1979	11	27	29
1979	4	10	11
1980	16	14	17
1981	23	11	7
1982	20	8	8
1983	29	5	6
1984	49	12	27
1985	36	15	17
1986	53	17	25
1987	33	13	20
1988	62	16	28
1989	49	21	27
1990	95	27	39
1991	187	66	105
1992	237	56	106
Totals	904	318	472

NOTE: These figures for research alliance start-ups must be compensated for terminations to arrive at the cumulative total each year, as shown by the top shaded area in Figure 2.1. Like Figure 2.1, these figures represent the totals from the CATI and SDC databases.

Why is this increase happening? What benefits are firms and their executives perceiving from alliance participation? If alliances are truly advantageous for private firms, research alliance participation should be correlated with increases in innovations and improved products. One would also expect such benefits to then lead to increased profits and market share.

This research was designed to test for such results, because this accelerating trend of corporate research alliances is inconsistent with the assumptions underlying the appropriability justification for

15 See Table 4.4 below.

government subsidies, strict anti-trust enforcement, and *neomercantilist* trade and technology policies. On the other hand, the trend is consistent with a modified theory of transaction cost economics, a learning perspective of innovation, corporate organizational learning strategies, including an integrated view of the research process (as opposed to a sequential pipeline model). Moreover, because many of these alliances are international in character, these trends are consistent with *transnational* trade and technology policies.

GROWTH OF RESEARCH ALLIANCES INCONSISTENT WITH GOVERNMENT TECHNOLOGY POLICIES AND ASSUMPTIONS

Appropriability Rationale

The early Arrow and Nelson appropriability analysis (Arrow, 1962; Nelson, 1959) justifying large-scale government subsidies for military and civilian research efforts was based on the idea that since firms cannot capture, or appropriate, all of the returns from their inventive efforts, insufficient research is performed by private-sector firms. Moreover, since the social rates of return, or in other words the public benefits from basic research, far exceed what firms can individually appropriate, government has a legitimate role in subsidizing basic research efforts.

One key assumption made in the Nelson and Arrow analysis is that firms in society are non-cooperating. Information leakage occurs, but explicit firm-based cooperation would violate the anti-trust principles and laws as then implemented. For the Nelson and Arrow analysis, discrete firms are assumed to perform individual research, from which new technologies and products emerge which are protected by intellectual property laws. A portion of the total returns from the innovations are eventually captured by the firms. In such a society, the analysis indicates that large subsidies are required to boost the rate of research and eventual enhancement of usable technology.

Without the assumption of discrete firm research, this appropriability analysis breaks down. Richard Nelson has written of the weaknesses of the analysis and suggested the importance of low-cost exploratory research.

> As the analysis began to be more sensitive to the details, however, economists came to recognize that the situation is much more complex.... It began to be understood...that [patents and industrial secrecy] led in some cases to duplicative or near-duplicative R&D efforts by firms, which yielded little net social value. This phenomenon cast doubt on the earlier logic that private enterprise, if unaided by subsidy or monopoly, would spend "too little" on R&D, and it called attention to inefficiencies of the allocation of R&D among different kinds of projects that the industrial R&D system would generate. Also, economists came to recognize better that because of the uncertainty that surrounds efforts to take a grand step forward in technology, it may be desirable to encourage the exploration of a variety of different approaches, without premature heavy financial commitments to any. (Nelson, 1983).

Such exploratory research is facilitated by cooperative networks of research alliances where duplication is minimal. Moreover, the innovation process is much more complex than contemplated by early appropriability analysis. Crucial factors for successful R&D may include feedback from the market, subsequent innovators, and alliance partners; the structure and organization of the research system within the economy; and the firm's internal system of communication and organization.

Neoclassical appropriability analysis is silent on these points. To the extent that feedbacks and communication flows from alliance partners and customers, and organizational structures, are significant factors, the degree of private appropriability should be of much less concern both for private R&D investment decisions, and public subsidization measures for private research.

These results depend critically on the anti-trust environment and degree of cooperativeness among firms, as well as among firms and their network of suppliers and customers.

Anti-Trust Enforcement

For many years in the U.S., anti-trust enforcement prohibited any joint corporate research activity. Even when enforcement waned during the years between the first and second world wars, firms were not free to form cooperative research activities among themselves, although joint

research activities with universities became commonplace. (Mowery, 1992; Rosenberg, 1972). During the Reagan presidency when anti-trust enforcement was de-emphasized, firms began forming cooperative research alliances at a high rate. The cooperative activity accelerated after 1984 when Congress passed the National Cooperative Research Act. This Act created a safe harbor from treble damages for research cooperation and established a rule of reasonableness for anti-trust evaluation of research cooperation. Consortia, joint ventures and strategic alliances which file a disclosure notification with the Justice Department are granted a safe-harbor from treble damages, limiting any anti-trust enforcement recovery to actual damages.[16] This protection applies, however, only to activities within the scope of the filed notification. In 1993, under the current administration, these anti-trust exemptions were expanded to include protection for joint manufacturing ventures.[17]

Recently, however, the Anti-Trust Division of the Justice Department has targeted high-tech business, including their joint research activities, for very close anti-trust scrutiny. As some have commented, the Division is moving to become the most active trust-buster since the days of Franklin Roosevelt. (Jenks, 1994). It has hired many new attorneys. It is seeking authority to subpoena documents from foreign companies and is particularly targeting mergers of R&D assets. Because of the benefits of competition, the Division seems to be operating under the assumption that duplicating R&D assets is better than cooperation or merger. And as one reporter wrote, Justice "is positioning its anti-trust wrecking ball to tear [private-sector research partnerships and consortia] down." (Jenks, 1995). The Division apparently fails to consider the chilling effect such policies might have on innovation rates and capabilities.[18] Indeed, this

[16] See 15 U.S.C.A Sections 4301 through 4306, and especially 4303.

[17] National Cooperative Production Amendment of 1993. P.L. 103-42.

[18] The economic basis of such anti-trust enforcement is static economic analysis that fails to account for the dynamic realities of the innovation process. Moreover, U.S. anti-trust policy has long failed to account for the additional competition created by the global technology flows and trade.

"radical shift" in U.S. technology policy back to pre-1980s policies threatens to vitiate the 1984 Cooperative Research and Development Act and dampen the formation of consortia such as the Microelectronics and Computer Corporation (MCC). (Jenks, 1994).

This trend is clearly inconsistent with the cooperative research direction so evident in the private sector. But the anti-trust enforcement trend is related to other Administration policies that can be classified as neomercantilist.[19] The increased anti-trust effort is related because one aim of such enforcement is to break up foreign alliances, for example those involving only Japanese, or only German, firms, which are perceived as creating anti-competitive market conditions for U.S. firms.

Neo-Mercantilism

So while the overall Administration objective may be to enhance domestic and international competition (Jenks, 1994), the apparent motivation is to level the playing field for U.S. firms. As such, they are neomercantilist policies, or policies designed to enhance the commercial success of domestic firms. They include managed trade; reprisals for perceived dumping of foreign goods at less than the cost of production, foreign subsidies for exports, and foreign alliances; restrictions on domestic investments by foreign entities; targeting of public investment funds on "national champions;" and government scrutiny of transborder alliances to ensure national advantage and market position. (Golden, 1993; Moran, 1993). Along with these are policies that preclude foreign firm involvement in subsidized national research consortia, such as SEMATECH and the Partnership for a New Generation of Vehicles.

Clearly such policies are inconsistent with the trends of proliferating private sector alliances. Either governments allow firms to associate and form alliances freely, or they don't. If not, it is often due to policies aimed at bolstering national economic advantage. The political forces demanding such advantage set the stage for the fundamental policy dilemma described above in the Preface: How can a

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[19] Such as its strong managed trade efforts. (Matsuo, 1994).

nation maintain relative competitive strength if it permits unlimited cooperative research alliances?

ALLIANCE TREND CONSISTENT WITH TRANSACTION COSTS AND LEARNING THEORIES, AND TRANSNATIONAL GOVERNMENT POLICIES.

Transaction Cost Theory

Transaction costs theory originated with Coase who explained the existence and nature of firms by their lower costs than comparable market-based transactions. As more fully developed by the works of Oliver E. Williamson (Williamson, 1975), transaction costs theory assumes that costs arising from opportunistic behavior are possible in many transactions. In addition, the theory assumes bounded rationality of the parties to transactions, and posits that the greater the specificity of assets involved in a transaction, the greater the risk of undetectable (due to bounded rationality) opportunistic behavior by other parties to the transaction. Facing opportunistic threats, firms will prefer to internalize activities rather than engage in costly and uncertain market contracts.

Opportunistic behavior is assumed by Williamson when a small numbers of firms are involved in a particular market transaction. (Williamson, 1975, 27). This assumption is an extension on the traditional assumption that economic agents are guided by self-interested behavior. The extension is that individuals engage in strategic behavior. In other words, opportunism refers to "a lack of candor or honesty in transactions, to include self-interest seeking with guile." (Williamson, 1975,9).

As an explanation of why firms innovate and form alliances, transaction cost theory has several significant weaknesses. These include a failure to explain why firms innovate (Lundvall, 1988), a failure to explain the length and stability of alliances, and the evolution of alliance networks (Mody, 1993), and a reliance on static analysis and inability to account for the positive opportunities arising from alliances (Foray, 1991).

A modified version of the theory, however, is consistent with the increasing numbers of alliances. Ashoka Mody of The World Bank recently presented a framework of the learning nature of strategic alliances and asserts that his insights are complementary to, and an extension of, transaction cost analysis. (Mody, 1993). Mody proposes that the opportunistic costs of alliances are balanced by the flexibility they offer. He views alliances as a Bayesian experiment in which the outcome of each period (i.e., the learning about the environment and the partner) becomes the basis for further action. Because "alliances have only weak incentives to prevent cheating or opportunistic behavior," they should be viewed as "experimental organizations that trade off the acquisition of knowledge against potential losses due to cheating and opportunism." Over time, the probability of either dissolving the alliance or merging the cooperating firms will increase.

Another transaction cost explanation for alliances was outlined by Ciborra, who asserts that alliances are experiments in openness, that "enhance [firms'] learning capabilities and...augment their trustworthiness." In other words, contrary to transaction cost prescriptions that demand internalization and control mechanisms to block opportunism, learning requires trust and an absence of such controls. Therefore, "by denying the reasons for internalization of transactions, ...alliances represent one of the few institutional arenas within which to experiment with such innovative behavior and the only one that can lead to trust and innovation" (Ciborra, 1991, 59). Like Mody, Ciborra also asserts that firms enter alliances to reduce uncertainty. In Ciborra's view, alliances control the complexity of the environment and simultaneously augment the organizational capabilities of the firm.

Thus, both Mody and Ciborra view alliances as *learning experiments* about the trustworthiness or opportunistic behavior of alliance partners. Therefore, one dimension of this research will be to explore the relative degree of executive concern for (1) the economic motives

for alliance formation,[20] (2) the learning opportunities they present, and (3) the threat of opportunistic behavior.

Innovation as Learning, Organizational Learning Strategies and Integrated R&D Design

The growth in the numbers of research strategic alliances is clearly consistent with a view of innovation as a learning process; with corporate strategies that emphasize the importance of individual and organizational learning; and with R&D strategies that integrate all research, development, and manufacturing phases into the R&D process, along with inputs from alliance partners, suppliers and customers.

The innovation process has been viewed by many as searching and "learning." As one technology policy economist has stated: "In an essential sense, innovation concerns the *search* for, and the discovery, experimentation, development, imitation, and adoption of new products, new production processes and new organizational set-ups." (Dosi, 1988)(emphasis added). This is consistent with the view that invention is the creation or discovery of new technological knowledge, and innovation is the embodiment of this knowledge in actual products or processes. (Norris & Vaizey, 1973).

Lundvall views innovation as an interactive process of learning. (Lundvall, 1988). Sahal describes technical progress as a process of learning by scaling.[21] (Sahal, 1985). Dosi points out that the central focus of evolutionary theoretical studies of innovation is the "nature, procedures and effects of innovative learning." (Foray, 1991) (Dosi, 1991). The most succinct statement comes from Zysman: "Technology's evolution is a *path dependent process of learning* in which opportunities

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[20] These include risk sharing and cost reduction, accelerating the return on the investment, sharing investments in manpower and equipment, and the creation of efficiencies with economies of scale and specialization.

[21] In describing the evolutionary nature of technological trajectories, Sahal notes that innovation originates in learning to overcome the constraints that arise from the process of scaling the technology. The scaling refers to changes in the size and shape of technology objects. Learning accompanies changes in the scale. For Sahal, innovation is the process of increasing or decreasing the scale and overcoming the natural limitations to such scale changes.

for tomorrow grow out of research, development and production undertaken today." (Zysman, 1992)(emphasis added). Path dependency implies the importance of cumulative learning and iterative innovation.

To the extent innovation is a learning process, corporate strategies that emphasize the importance of broad information acquisition and efficient information processing should be more successful. Such strategies come under the rubric of organizational learning and include efforts to integrate the entire R&D process.

Despite the strong relationship between learning and innovation, extensive studies of successful and unsuccessful innovations indicate there are "no simple single-factored explanations" for innovation success. Rather, "success is a matter of competence in all functions, *and of balance and coordination between them,* not of doing one or two things brilliantly well." (Rothwell, 1992, 224)(emphasis added).

Important factors are "the establishment of good internal and external communication; effective linkages with external sources of scientific and technological know-how; [and] a willingness to take on external ideas." In this regard, Rothwell comments as follows:

> ...whether the impetus for new product development derives from marketing or from R&D is less important than the fact that both departments, along with manufacturing, are involved in project appraisal and project definition right from the start. With successful innovators the emphasis is on interdisciplinary teams with maximum sharing of information across functions. This ensures that customer needs remain the focus of R&D activity. (Rothwell, 1992,225).

Moreover, customer focus is identified as a separate key factor: "Strong market orientation; emphasis on satisfying user-needs; efficient customer linkages; [and] where possible, involving potential users in the development process." Rothwell's report went on to prescribe that "would be innovators should take pains to identify and interact with *leading-edge* customers during and following new product development." (Rothwell, 1972).

This is consistent with von Hippel's research which found that users constitute important, and in some cases the predominant, innovators within technology intensive industries. (von Hippel, 1988).

One example of this phenomenon is the study of the audio equipment and microcomputer industries by Langlois and Robertson who found that attempts to appropriate rents with firm-specific appliance-like hardware and software solutions failed, while those firms prospered which opened their equipment to third party developers, thereby allowing for greater networked learning among producers and consumers. (Langlois & Robertson, 1992). The surge in Microsoft Windows and IBM PC compatible clone computers relative to the technologically superior, but, until very recently, strictly proprietary Apple Macintosh, is another example of this phenomenon.[22]

Consequently, good communication flows among customers (both existing and potential), scientists, alliance partners, marketing personnel, engineers and product designers may be one key to innovation success. Such flows are also the hallmark of organizational learning. (Grossman & Helpman, 1994; Walker, 1994). And organizational learning has become an increasingly important methodology for analyzing and understanding responses to environmental turbulence and complexity, the primary characteristics of the innovation process. (Griliches, 1984).

As Rycroft and Kash point out, success with "today's complex innovation processes, constant risk and uncertainty, multiple feedback loops, surprises and mid-course adjustments" requires nothing less than "users, suppliers, and assemblers to be intimately linked to manufacturing, design, research and development, and servicing." Consequently, in all phases "whether the purpose is to monitor outside research or constantly changing user needs, maintaining information flows is crucial." (Rycroft & Kash, 1994, 253).

This kind of learning is fast-paced, ever-searching, mutually supportive and largely unpredictable, though not unfocused. As one author wrote:

> To meet the challenge of technological acceleration firms must learn faster and more effectively because the most successful innovative organizations are also high performance learning systems. Moreover firms must create different ways of

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[22] Not surprisingly, recently Apple finally announced a deal involving IBM and Motorola to develop a common standard architecture that will be licensed to all clone makers. (Hall, 1994).

learning and of "learning how to learn" under these unfamiliar, dynamic environmental conditions. (Meyers, 1990).

The Trust Problem

The problem is that efficient and informative communication flows require trust and a culture of sharing (Peters, 1994). And attitudes of trust and sharing are, at first blush, inconsistent with the traditional (neoclassical) economic assumption that one's ally will act opportunistically if allowed. If an executive assumes her firm's alliance partners will take advantage of her company, that executive may take preventative measures that signal partners that she anticipates cheating. These signals may include detailed contracts with explicit liquidated damage provisions for a host of possible wrongs. Such signals may trigger a reciprocal lack of trust that leads to the very partner opportunism against which the preventative measures are designed to protect.

That is why the Mody and Ciborra view of alliances as learning experiments is important. Firms may indeed enter into alliances with the potential learning and economic gains in mind, but cautious of the risks of opportunistic partner behavior. As an alliance progresses, the participating firms not only learn about the markets and innovation opportunities, but, equally important, about the trustworthiness and reliability of their partners. Hence, one aspect of this research explores the tension between attitudes of trust, learning and sharing and those of concerns for opportunism.

One theory that may tie many of these strands together is resonant organizational learning, suggested by the author.

Resonant Organizational Learning

As indicated by the above background, one way to measure the impact of learning strategies is to examine the degree of a firm's learning capability in terms of its external and internal communication connections and flows, and compare these with a measure of the firm's innovativeness.

I have suggested elsewhere that organizational learning will be optimized if the following conditions are met:

> 1. Dense communication linkages and organizational coupling internally as well as externally to the organization; 2. efficient coordination and communication systems and flows among the linked individuals and entities; facilitated by 3. cooperative organizational cultures characterized by joint, as opposed to relative, gain seeking behavior; and 4. continuous multilateral efforts by all linked individuals and entities to increase the linked knowledge base, improve learning skills and provide and respond to feedback to enhance the system-wide learning. (Walker, 1994).

The basic idea of this theory, which I have called resonant organizational learning theory, is that a firm's learning capability depends both on the quality and efficiency of its external connections and on the information processing efficiency of its internal organizational structure, including the individuals themselves. If multiple communication connections exist, and the communication flows are unimpeded by constraining hierarchy or non-cooperative cultures, useful information will flow efficiently and learning will be optimized, both at the individual and organizational levels. Moreover, the strength of the coupling between individuals within the firm, and among the firm and its customers and suppliers will be adjusted efficiently to meet the information processing demands. These self-organizing adjustments are necessary because a system too tightly coupled may enter a region of endogenously generated uncertainty, or chaos. On the other hand, if the coupling is too loose, insufficient information will flow and learning will be sub-optimal.

In the context of research and development in the global economy as we know it, this model is essentially a fully integrated model of innovation. In the model, firms form cross-functional teams to shepherd innovation projects and fully integrate all in-house innovation processes. They couple closely with customers and suppliers, and establish various forms of research alliances, as required, with competing or non-competing firms which have mutual or complementary interests. This model represents, in fact, a rationale for the kind of globally integrated firm that seems to be emerging.

Obviously, to state such a theory raises many questions. What would be the result of an entire population of firms poised on the resonant edge of chaos?[23] What would be the dynamics of a mix of firms, some committed to learning strategies, others locked into traditional competitive rational man thinking? Would the cooperating firms attract other like minded firms and join together to isolate (or inoculate) themselves from invading non-cooperating firms? Game theory might shed some light. Sophisticated population ecology simulation models, possibly coupled with concepts of evolutionary economics, may begin to provide some answers.

This research focuses on a narrower question: What is the relative innovation performance of firms that engage in multiple alliances compared to that of those which do not? Empirical evidence may provide evidence sufficient to reach first order conclusions about the resonant learning theory. Positive results may be sufficient to motivate further and less aggregated research of specific firms or industries, as well as theoretical modeling.

Transnational Policies

Finally, the alliance trend is consistent with national policies designed to increase transnational integration. Such policies include liberal multilateral trade policies, open policies for domestic investment by foreign firms, the use of R&D credits by both domestic and foreign firms doing business in the U.S., and a presumption in favor of alliances. (Golden, 1993; Moran, 1993). In addition, transnational policies require a permissive anti-trust environment for cooperative alliances.

The more that firms form alliances, the more information is available to them through their network of collaborators and customer

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[23] The "edge of chaos" term is from the work of the Santa Fe Institute. (Lewin, 1992). In the resonant organizational learning theory this term represents the balance point, where learning is optimal, between coupling which is too close and coupling that is too loose. When coupling is too tight, the system falls into a region characterized by chaotic fluctuations. When coupling is too loose, information flows are limited and learning diminishes. Hence, the importance of this optimally responsive boundary region.

base. When the increased information from customers and partners is efficiently processed by integrated innovation teams and networks within firms, it should be more quickly incorporated into new products.

The policy issue is whether transnational policies will stimulate the innovation learning process domestically, as well as on a global basis. Stated in the negative, the issue is whether neo-mercantilist policies and strict anti-trust enforcement would have a negative impact on the innovative learning of private-sector firms.

SUMMARY

This research was designed to test whether private innovation efforts benefit from cooperative research, domestic and international. If a positive correlation is found between cooperation and innovation output, and cause and effect established, the implications would be supportive of transnational integration policies.

While the alliance trends are consistent with transnational policies, the research has also been designed to test the relative strength of learning determinants, opportunism concerns, and organizational learning designs and practices on innovation performance and transaction cost problems.

The correlation between alliance experience and innovative performance can inform policymakers of the relative merits of transnational and neomercantilist policies. Obviously, it does not necessarily follow that because private-sector international research alliances may lead to increased innovation, transnational policies will lead to national prosperity (particularly if measured relative to other countries). However, a positive correlation between international alliance activity and innovation would suggest that neomercantilist policies may lead to reduced innovation rates (relative to international competitors), which would eventually have negative repercussions for the national economy.

Last, the relative strength and impact of the alliance, R&D spending, learning, opportunism and economic focus variables on performance can inform corporate executives of how much weight to put on these factors when evaluating alliance opportunities.

3. RESEARCH PLAN AND HYPOTHESES

POLICY ISSUES

The major themes of this project revolve around choices and their consequences: Should the government base its technology policy on neomercantilist strategies or, alternatively, on transnational concepts? In other words, should the U.S. seek to maintain or enhance global industrial competitive leadership by protecting domestic firms from foreign competition and subsidizing national industries and consortia, or, should the U.S. encourage greater R&D and production collaboration without regard for the nationality of the participants, or for the competitive status of the U.S. and its firms?

The Relation of National Policies to Corporate Policies

While these choices are at the government policy level, similar choices face corporate policymakers and strategists. To what extent should firms seek opportunities to enter into research alliances? How will such alliances affect their long range innovativeness and profitability? And does the mix of domestic and international alliance partners make a difference?

As very little, if any, data exist in sufficient detail to test the government level policy issues, the research focuses on the firm-level performance issues. And from the firm-level data, I wish to draw inferences regarding the national policy issues. Drawing such inferences is consistent with the notion of the national innovation system, or national "enterprise" metaphor the Administration uses.[24]

So rather than trying to address this issue in its entirety, I focus on the process of private-sector innovation and the benefits and risks of collaborative R&D alliances. To narrow the scope of the

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[24] President Clinton's new Technology Policy document, *Science in the National Interest*, uses a similar term, "technology enterprise," to describe the system of government, universities and private enterprise devoted to innovation, research and technology development. (Clinton & Gore, 1994)

research further, the initial research design targeted semiconductor, aerospace and automotive manufacturing firms that spend more than $1 million annually on R&D.[25]

The comparison of the U.S. and European semiconductor firms will be particularly important. During the last decade the European firms have pursued an independent European strategy, while the U.S. firms have entered into multiple alliances with other U.S. semiconductor firms, as well as with Japanese firms.[26]

Why These Policy Issues Are Important

The policy issues are important because of (1) the importance of technology for prosperity in today's global economy and (2) the high level of government intervention that continues in the science and technology arena. They are more salient now that the new Republican controlled Congress may be revising the Administration's policies.

These policies include increasing subsidies for basic research and establishing government sponsored consortia such as the Partnership for a New Generation Vehicles. These are coupled with tough trade restrictions and hard-nosed trade negotiations designed to selectively open international markets while protecting the U.S. market from "dumping" and other so-called unfair trade practices.[27] Simultaneously, the Anti-Trust Division is increasing its scrutiny of high-tech research collaboration.

The Administration's policy objectives are threefold: (1) world leadership in science and technology, (2) national economic competitiveness, and (3) pure competition on a global scale. (Clinton & Gore, 1994). Ironically, as the government shifts its technology policies from military based research to commercial technology leadership and economic competitiveness, private-sector firms are becoming ever more cooperative and integrated with global cooperators:

[25] However, as will be discussed later, R&D spending data are published for only a small portion of firms in the financial database to which I had access. Consequently, I cast my net widely, and started with all firms in the relevant SIC code areas for which the financial data were available.

[26] See Levine (1992).

[27] See Matsuo (1994).

Strategic alliances are multiplying, international trade is growing and international communication flows are accelerating.[28] This trend will only continue with the new General Agreement on Tariffs and Trade (GATT). But some of the Administration's technology policies do not seem consonant with the accelerating rates of interfirm cooperation occurring as the globalization increases.

It seems clear from the studies of innovation and organizational learning cited in Section 2 that any diminution of cooperative research alliances may have a negative impact on private-sector innovation rates. Moreover, trade opportunities may be restricted. Worse yet, as noted by Golden, neomercantilist policies that attempt to protect national firms may work to isolate domestic workers from high-paying jobs available in the global network. (Golden, 1993, 103). At the very least, such isolated firms will not reap the tremendous innovation stimulus reaped by producers cooperating and competing with multiple global competitors. (Lewis, 1993).

RESEARCH QUESTIONS:

To provide empirical evidence for drawing desired policy inferences, I focused this research on the following specific questions:

1. What is the effect of research and development alliances on the innovation and profitability of the firms and industries studied? And, how do international R&D alliances affect these results?
2. How do organizational learning factors (number of alliance linkages, internal organizational learning strategies, the quality of communication flows from alliance executives, and executive attitudes toward alliances) affect the innovation and profitability of the firms and industries studied?
3. What effect do (a) experience with corporate alliances, (b) executive attitudes and (c) communication quality from alliance partners have on the perceived success and transaction costs

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[28] For an excellent discussion of the global interdependence of the national innovation systems, see Niosi & Bellon (1994).

problems of alliances, as well as on the formation of new alliances?

Primary Definition and Thesis of the Research

"Innovations" are defined as new products, product enhancements or processes which are sold to customers or used in the manufacture of products for customers. Thus, innovations are more than mere inventions, and they may be either new products or processes.

As described in Section 2, the innovation process itself is usefully described as a mutual learning experience involving science and scientists, engineers, product designers and developers, manufacturers, marketers, competitors and customers. This process may be enhanced by increasing the information flows among all of these groups, thereby increasing the speed and scope of the mutual learning process. A key variable may be the extent of the customer base. Certainly, international alliances increase the size and diversity of a firm's customer base. *Thus, private-sector alliances, including international alliances, in an environment of relatively open trade flows and efficient modes of communication, should enhance a nation's innovation capability.*

Research Plan

The research examines the recent financial and innovation performance of aerospace, automotive and semiconductor firms. These sectors are important in each country or region where production is centered. The frequency and scope of innovations, as defined in this research, vary among these sectors, as does the amount of direct government support and market protection.

While the automotive and semiconductor sectors have been studied by many researchers looking at the determinants and structure of global alliances, (Burgers, Hill, & Kim, 1993; Haklisch, 1986; Miller, 1994), the aerospace sector has not. More importantly, in none of the prior

studies of these sectors have the researchers correlated alliance experience and innovation outcomes, however measured.[29]

Closely Related Relevant Research

Two studies are closely related to this research.

The first (Berg, Duncan, & Friedman, 1982) examined the issues of why firms enter into joint ventures and the impact of joint ventures on R&D spending and profitability. However, the analysis was based on rather old joint venture data (1971-1973). The period for the analysis preceded by 10 years the surge in alliance activity explored in this research project. Among other findings, these early researchers found a positive correlation between firm size and technologically oriented joint venture participation rates. However, they found no significant long-term impact on profitability of joint venture activity in any industrial sector. However, by aggregating all data across 19 industry groups, they found that R&D joint ventures have a negative impact on industry-average rates of return, but other forms of joint ventures (those not oriented towards knowledge acquisition, such as production and marketing joint ventures) have a positive impact. The researchers attributed the negative impact of knowledge-acquisition R&D joint ventures to the enhancement of competition, which creates negative pressure on profits.

The second study is more recent and closely connected with this research, as it is based on the CATI data. (Hagedoorn & Schakenraad, 1994). Hagedoorn and Schakenrad used the CATI data to estimate economic performance and innovativeness as a function of alliance participation. They studied three broad sectors: information and electronics, mechanical engineering (including automotive, aviation and defense), and oil and chemical corporations. The primary dependent variables were profit rate (profits divided by sales) for the years 1984-1988 and patent intensity (number of U.S. patents divided by average sales) for 1982-1986. For independent variables, they used (1) the size of firms

[29] But a recent study on the biotechnology industry does find that research cooperation has a positive impact on innovation. (Shan, Walker, & Kogut, 1994).

as measured by sales and number of employees, (2) the strategic partnering weight (logarithm of number of strategic partners for 1980-1987 divided by the logarithm of average sales for 1982-1986), (3) the technology-to-market mix of alliances (logarithm of number of R&D alliances divided by the logarithm of the number of market oriented alliances), and (4) the generation to attraction ratio (the ratio of the number of generative strategic linkages to the number of absorptive or attractive linkages). The latter information comes from a field in the CATI data that describes the direction of technology flow. Firms participating in alliances are seen as either providing (generating) or receiving (absorbing) technology, or both.

Hagedoorn and Schakenraad use a linear path analysis modeling program, LISREL (linear structural relations modeling) to eliminate heteroskedasticity and multicollinearity errors, and improve the specification of cause and effect variables.

One weakness of their study is that most of the data cover simultaneous periods. The patent data cover the years 1982-1986 which are bracketed by the alliance data for 1980-1987. The profitability data cover the last half of the alliance data period, 1984-1988. The ability to establish cause and effect from alliances to innovations to profits seems severely constrained by these somewhat limited periods for the research variables. If firms engaged in alliances take time to develop patentable inventions which eventually become marketable innovations that affect the bottom line, then this design doesn't seem capable of capturing the real impact of alliances on performance variables. At best, this design can be seen as a cross-sectional look at correlations among alliances and performance variables.

Nevertheless, several of the Hagedoorn and Schakenraad findings are relevant for this research, despite the time period limitations of their data:

- Firms that obtain numerous patents are heavily involved in strategic partnering. And information technology firms have a higher cooperation intensity than process industries.
- US firms are less inclined to use strategic cooperative strategies than Japanese and European firms.

- European firms are more oriented toward absorptive alliances (or receptive of technology transfer from their partners) while Japanese firms are more likely to generate the technology transferred to alliance partners.
- The size of the firm is positively correlated with its strategic partnering intensity.
- A firm's patent intensity and propensity to form R&D alliances are associated with higher economic performance.
- While the analysis did not show a direct impact of strategic alliances on economic performance, companies attracting technology through their alliances and companies concentrating on R&D cooperation have significantly higher rates of profit. This relationship appears to be indirect, rather than direct, and "can to a large extent be explained by the differentiation of firms and sectors with regard to...technological opportunities." (Hagedoorn & Schakenraad, 1994, 303).

The connections between (1) patents and strategic partnering, and (2) size and strategic partnering are supported by this dissertation research. The one-directional relationship between partnering and patent intensity, and economic performance is also supported. In this research, the reverse relationship (from economic performance to alliance behavior), is negative. No attempt is made in this research to account for the degree to which firms acquire or transfer technology. But with the longer time periods of the alliance data, this research may yield better discrimination of the correlations among alliance behavior, and innovation and economic performance. In addition, this research explores the impact of alliances depending on whether they are domestic, confined within the European Union (E.U.) trading bloc, or are international (cross-trading blocs).

Potential Data Sources

An evaluation of the available data at the commencement of this research indicated that a variety of data would be necessary to explore the research questions posed, including financial data, innovation data and alliance data. Financial and patent information was readily

available. However, data on innovations as defined above were not. Also, at the time this research commenced, alliance data were either too expensive or not releasable to RAND. Consequently, I began this research planning to conduct an extensive survey of firm innovation and alliance experience. As will be explained below in more detail, completing such a survey project would not have been feasible. Circumstances changed, however, and I was able to test the following hypotheses using (1) patent, alliance and financial data from existing databases, and (2) information about organizational learning constructs and executive attitudes from an abbreviated survey questionnaire.

HYPOTHESES

The research hypotheses are designed to test the effect on innovative and financial performance of external linkages (alliances), communication quality, degree of internal integration, executive attitudes toward cooperation and organizational learning practices.

The Impact of Alliances, Domestic and International.

> 1. Technology-based firms which pursue an independent research strategy will be less innovative and earn lower returns than firms that engage in multiple R&D alliances and consortia, including international alliances.

It seems clear that firms which enter into multiple alliances are connected with a larger customer base than firms which pursue an independent research strategy. Therefore, based on von Hippel's finding that a large portion of innovations originate with customers (von Hippel, 1988), the larger customer base should result in greater innovativeness. Moreover, the resonant organizational learning theory, described in Section 2, predicts that firms with greater numbers of alliance connections will be more innovative. Because the information gathering, searching and processing capabilities of alliance firms are increased, their ability to develop successful innovations should be substantially enhanced.

If alliance connections with multiple firms are beneficial, alliances with international firms would provide even more leverage, as

the market connection is broader. Moreover, international alliances may be more likely to create joint gains opportunities than domestic-only alliances, as the size of domestic markets may be viewed by competing partners as fixed. To the extent that international alliances actually create increased joint gains opportunities for both firms, they may be more conducive in fostering genuine cooperation and high levels of trust that lead to increasing quality of communication, learning and accelerating innovation. This leads to Hypothesis 1A:

> 1A. International alliances will have a greater impact on innovation and earnings than will domestic alliances.

According to much business literature, in today's global economy, innovativeness is the key to profitability and growth. (de Pury, 1994). Clearly, there are many other factors which affect firm profit levels. But long range profitability is seen as highly dependent upon innovations.

While patents do not rise to the level of innovations, they are a sufficient proxy for innovation. Lerner has shown that firm value in the biotechnology sector is correlated with the breadth of patents obtained.[30] (Lerner, 1994).

If value is correlated with profitability and the expectations of future profitability, and if more alliances are correlated with increased numbers of patents, and broader patents lead to increased value one might expect more alliances to be correlated with increased profits. However, the connection appears tenuous, because the linkage between alliances and profits is more distant than that between research alliances and patent production.[31] Moreover, an increased number of

[30] Lerner found that a one standard deviation increase in average patent scope was associated with a 21% increase in firm value. Valuation was measured during financing rounds in the venture capital investment process. Patent scope was measured by the number of International Patent Classification (IPC) four-digit subclasses to which each patent is assigned by the U.S. Patent Office.

[31] As suggested by the Hagedoorn and Schakenraad study described above.

patents certainly may not imply increased breadth of patents.[32] Nevertheless, the relationship is plausible and merits testing.

The Impact of Organizational Learning Connections and Communication Flows

> 2. Firms operated to acquire extensive technological information more rapidly (multiple external alliances, better external communication flows and favorable executive attitudes toward alliance learning opportunities) and designed to process technological information better (integrated R&D, cross functional teams, better internal communication flows, and organizational learning practices) will be more innovative and profitable.

Organizational learning encompasses information acquisition and information processing. Firms with multiple alliances should acquire more extensive technological information more rapidly than firms with few or no alliances. Certainly, the quality of communication flows from alliance partners will also affect the rate of information acquisition. Moreover, the attitudes of a firm's executives toward alliances and alliance partners will likely have an impact on how cooperative and willing to share information partners will be.

In addition, the more alliances firms establish, the more closely connected with diverse markets and a larger customer base they will be. However, in order to generate marketable innovations, firms must process and act upon the ideas provided by customers and the information generated by alliances. Simple models of R&D efforts show that cooperation substantially reduces search and problem solving time requirements.[33]

Recent business literature suggests that the most effective firms may foster such cooperation with management systems specifically

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[32] Although the research data of this project do show a positive and statistically significant correlation between number of sector patents and the cumulative impact index, a measure of relative patent influence. This is not the same as the Lerner proxy for breadth, but it attempts to measure the same phenomenon.

[33] See Appendix C.

designed to enhance organizational learning. (Garvin, 1993; Schein, 1993; Senge, 1990).

One would expect the net result to be increased innovation. And with more innovation, firms should be more profitable.

The Benefits of Executive Mutual Learning Focus

> 3. Firms whose executives focus more on the learning opportunities presented by alliances will form more alliances and perceive greater success with their ongoing alliances.
>
> 3A. Firms whose executives focus more on the threats of partner opportunism will form fewer alliances and perceive more transaction cost problems with ongoing alliances.

This is the idea that pre-existing executive attitudes count. Executives who focus on mutual learning opportunities will likely convey to alliance partners a greater degree of openness, trust and cooperation. Partners are able to detect by action and inference such attitudes or their absence. And based on such perceptions, partners act and react. Favorable attitudes and signals will generate reciprocal cooperation. Resulting success should lead to increased numbers of alliances. On the other hand, suspicion will sow the seeds of distrust and opportunism. Eventual problems should have a negative impact on the formation of future alliances. Figure 3.1 illustrates this cycle.

This behavioral model assumes that executive predispositions toward the learning opportunities or the transaction cost threats of alliances will affect their firm's organizational structure, culture and communication patterns. Together these determine a firm's alliance choices and the signals sent to potential or existing alliance partners. Those choices and signals will be interpreted by the partners and affect their own alliance actions and signals. The mutual impact of the partner actions will largely determine the innovation results, which in

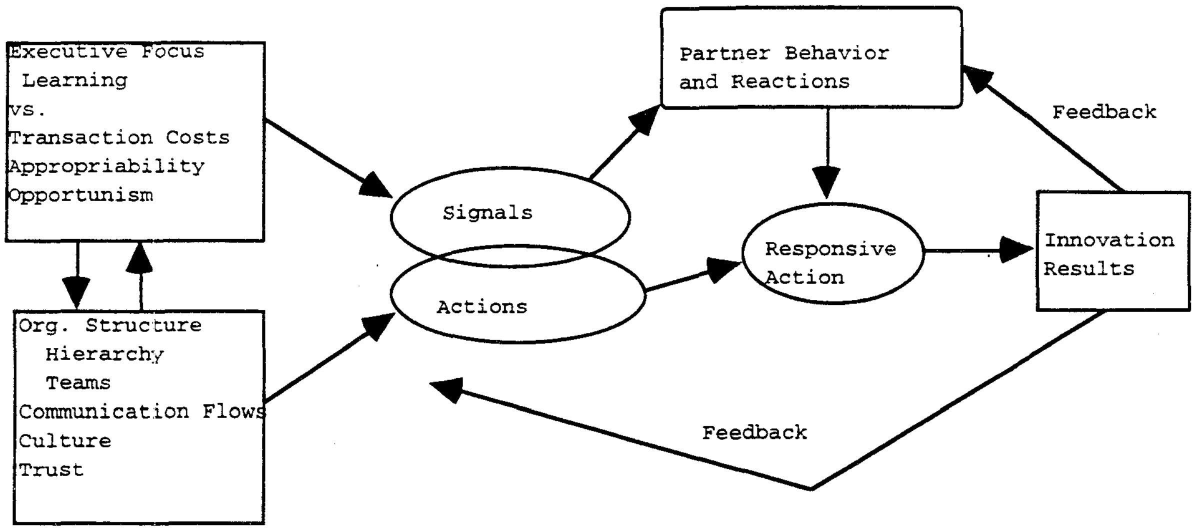

Figure 3.1—Behavioral Model of the Development of Trust or Distrust in Cooperative Alliances

turn provides feedback to the executives about the following: (1) the desirability of cooperative strategies, (2) the trustworthiness, integrity and intentions of the partner, and (3) whether it makes sense to continue cooperating.[34]

Thus, cooperation experienced executives should find more alliance success. Alliance newcomers or executives suspicious about alliances will likely perceive more problems with alliances and have negative attitudes about cooperation strategies.

The Impact of Quality Communication from Alliance Partners

> 4. Firms whose executives perceive better communication quality from alliance partners will form more alliances, and perceive greater success with their ongoing alliances and fewer transaction cost problems.

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[34] The feedback loops make this model consistent with Mody's theory of alliances as learning experiments, described above in Section 2. (Mody, 1993)

Many researchers have found communication quality central to innovation success. Rothwell identified as key "the establishment of good internal and external communication and effective linkages with external sources of scientific and technological know-how." (Rothwell, 1992). Ebadi and Utterback found that frequency, centrality and diversity of communication positively affect the success of technological innovation. (Ebadi & Utterback, 1984). Finally, Lind and Zund found communication frequency and richness to be important factors in predicting innovation. (Lind & Zmud, 1991).

In this research, communication quality from partners is an indicator of firm and executive skill in forming and operating R&D alliances. According to the model in Figure 3.1, firms whose executives are better at selecting partners and communicating trust, commitment and learning intent to alliance partners will perceive better reciprocated trust and cooperation. To estimate this complex interaction, the research focuses on the quality of information communicated to survey respondents from alliance executives. Increased quality should be indicative of greater alliance skills, resulting in more frequent and successful alliances and fewer transaction cost problems.

The Benefits of Cooperative Experience: Going Down the Learning Curve of Organizational Learning

> 5. Firms with more R&D alliance experience will form more new alliances, and perceive greater success with their ongoing alliances and fewer transaction cost problems.

This hypothesis tests whether there is a learning curve for cooperative research activities. Other researchers have written about this idea. (Westney, 1988). A German researcher used empirical data from a survey of German firms and found evidence that supports this hypothesis. (Brockhoff, 1992). I was interested to determine whether the same effect would be inferable from this project's data.[35]

[35] In addition, the data provide sufficient information to test the relative impact of the experience and communication variables.

Clearly, the research alliance and cooperation strategy is relatively new, at least within U.S. business culture.[36] And as in every complicated endeavor, practice in alliance participation should increase the ability of executives to select, negotiate and manage alliances well. Hence, we should expect to see positive effects of experience on the formation and success of alliances.

SUMMARY

Put simply this research focuses on whether firms which cooperate, domestically and internationally, are more innovative and profitable than those firms which do not, or those which are just beginning to experiment with research alliances. If experienced cooperating firms do show improved innovativeness and profitability, then it will be important to understand whether executive attitudes toward cooperation make a difference, and whether experience itself has an impact on perceptions of success and the frequency of forming new alliances.

Validation or support of the hypotheses posed would suggest several inferences. First, the potential for learning is an important variable in the calculus of deciding whether to form research alliances. Second, the role of appropriability and transaction costs in the innovation and cooperative research equation may be less than generally assumed by economists, political scientists and policy analysts. And third, Congress and the Administration should consider favoring transnational technology, anti-trust and trade policies that encourage widespread global cooperation over neomercantilist policies designed to enhance national competitiveness by boosting domestic R&D, protecting domestic industries and restricting domestic and international cooperation.

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[36] Official anti-trust exemption for cooperative research alliances has been available only since 1984. And as found by the *Wall Street Journal* and *Nihon Keizai Shimbun*, 31 percent of U.S. corporate chief executive officers (CEOs) still consider alliances dangerous. (Harbison & Pekar Jr., 1993).

4. ACQUIRING AND ORGANIZING THE RESEARCH DATA

During this project, RAND obtained extensive alliance data from two databases, providing data for a 14 year period: 1979-1992. With the quality of those data, I was able to reduce substantially the size of the initial questionnaire instrument.

Using the existing database data and the questionnaire data, I prepared five analysis databases which combine patent, alliance, finance and questionnaire data. This is the first time such extensive data have been combined for the three sectors studied: automotive, aerospace and semiconductors. The MERIT study described in the prior section looked at more sectors, but the alliance data covered shorter periods of time. Moreover, the combined alliance data cover a sufficiently long period, permitting exploratory longitudinal analyses.

Figure 4.1 shows the five databases, their contents and the relationship among them. Details about each of the data sets constituting these databases and how I obtained them and organized them follows.

SELECTING THE SAMPLE FRAME

Aerospace, automotive and semiconductor firms are identified by the following SIC numbers:

Aerospace:

3721: Aircraft Manufacturers

3724: Aircraft Engine Manufacturers

3728: Aircraft Miscellaneous

3812: Instruments, Avionics, Etc.

Automotive:

3711: Passenger Car Bodies

3714: Automobile Parts

Semiconductors: 3674

Initially, my objective was to select the entire population of U.S. and international firms in the three research sectors which spend more than $1 million annually on R&D. *Business Week's* "R&D Scoreboard" for

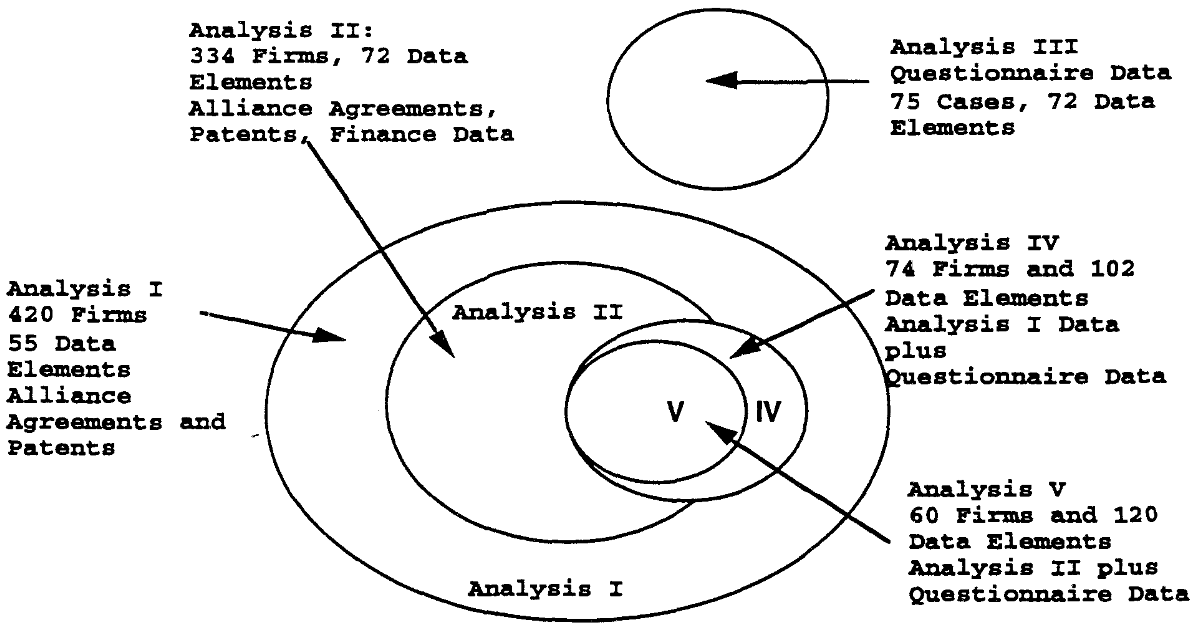

Figure 4.1—Five Cooperative Research Analysis Databases

NOTE: A complete description of the sources of data for these databases is found at the end of the section.

1993 lists the firms with more than $58 million in sales and more than $1 million annual R&D spending. Additional semiconductor and avionics firms were added to the database from the *High Technology Market Place Directory*. (Jacobs, 1992). To cast the net wider, firms in the *High Technology Directory* were included if their R&D spending exceeded $500,000 or a vice president of research and development was listed. Other firms were added by doing a search on the SIC codes in the Moody's Company Data database and Moody's International Company Database. The Moody databases contain only very sparse R&D data. Therefore, since eliminating firms on the basis of R&D spending thresholds was not feasible, I tentatively included all firms whose SIC codes were in the research sectors. Finally, I added a few firms in the aerospace industry from the *World Aerospace Directory*. (Kaulkin, 1993).

Where firms appeared in more than one SIC category, I assigned the firm to the sector for the primary SIC code and eliminated the duplicate entry.[37]

At the end of the process, 505 firms were in the sample frame, distributed as shown in Table 4.1. The questionnaire described below was sent to the identified vice presidents of research and development for all 505 firms. In addition, I sought to obtain existing patent and alliance data for the 505 firms.

Table 4.1

Initial Sample Frame

Sector	U.S.	International	Total
Aerospace	87	101	188
Automotive	58	118	176
Semiconductors	99	42	141
Totals	244	261	505

PATENT DATA

Longitudinal innovation data for the industrial sectors are not collected on a consistent basis anywhere in the world. Therefore, initially I intended to obtain innovation data for the sample frame firms with the questionnaire described below. Practical realities of survey questionnaire methods limited this research to using five-year patent data as a proxy for firm innovation.

U.S. patent data for all firms in the sample frame were obtained from CHI Research, Inc., a consulting firm which advises firms on technology and competitive trends using patent data. CHI Research publishes a patent database, called Tech-Line, consisting of the 1100

[37] Except in a couple of cases where firms were active in multiple sectors. Usually the duplication problem arose with automotive firms active in both parts and body manufacturing, or with aerospace firms active in aircraft engines and aircraft miscellaneous. In such cases, the duplicate entry was deleted. Exceptions were made where firms were active in completely separate automotive and aerospace sectors: for example, auto parts and aerospace instruments & avionics.

firms which are most active in obtaining U.S. patents.[38] Tech-Line is available on Dialog and Nexis. In addition, patent data for firms not in the Tech-Line database are available directly from CHI Research.

Of the firms in the research sample frame, 145 are in the Tech-Line database. Five-year summaries for each of these firms were obtained. These are organized by product groups which correspond roughly to three-digit SIC code levels.

Product groups are established by the U.S. Patent Office, which assigns each patent to the applicable product group. From the first page of each patent, CHI Research creates tables of summary data and computed indices that will be described below. For this research, I obtained Tech-Line summary tables for the following groups.

Product Group 43: SIC 366-367
Electronic Components & Accessories & Communication Equipment

Product Group 46: SIC 371
Motor Vehicles & Motor Vehicle Equipment

Product Group 54: SIC 372
Aircraft and Parts

Product Group 55: SIC 38
Professional and Scientific Instruments[39]

Product Group 57: All SICs combined
(The table for this group 57 contains the total patent activity for each of the firms in the Tech-Line database).

[38] The criteria for selecting firms for inclusion in the Tech-Line database are 10 patents in the past 5 years for electrical, chemical and pharmaceutical firms. For all other sectors, e.g., automotive and aircraft, 100 patents for the past 5 years are required for inclusion. In addition, CHI Research includes a few firms not meeting these criteria as exceptions based on judgment.

[39] This group includes avionics patents.

Each summary table contains the following data elements. The descriptions paraphrase CHI Research documentation.

1. Number of patents. This is a 5-year total of the patents within the specific product group that were granted to a company. Note that in many cases, this number is a small portion of the total number of patents obtained. However, the number of patents in Product Group 57 is the total obtained for all product groups for the 5-year period.

2. Percent of Patents (%): This is the percentage of patents obtained by the firm in the particular product group, and represents the relative emphasis placed by the company on innovation within the product group. It is the 5-year count of patents in the group divided by the total number of patents obtained by the firm, all multiplied by 100.

3. Patent Growth (%): The average annual compound growth rate of patents in the product group over the 5-year period. It is computed by subtracting the number of patents obtained in year 1 from those obtained in year 5 and calculating the compound growth rate. Negative growth rates are not reported.

4. Current Impact Index (CII): This index is a normalized technology quality indicator that measures how much relative influence a company's recent patents in the product group have had on technology patented in the 5-year period. To compute this index, the company's citation record is compared to the patent system averages. The annual CII is computed by taking the average number of citations *to* each of a company's patents obtained during the most recent prior five years in the product group *from* all patents granted (to all firms) in each "current" year, and dividing by the average number of citations to all U.S. patents in the same period from the "current" year. The 5-year CII is the weighted average of the values for each of the five "current" years in the 5-year period.

The expected value for CII is 1.0. CII values greater than 1.0 generally indicate the firm is patenting high impact technology. For example, a CII of 1.2 indicates 20 percent more

citations to a company's patents than expected. CIIs are computed on a product group basis, and some product groups are more highly active in patents and citing previous patents than others.

CHI Research needs a minimum level of patent activity in order to calculate a CII: 10 patents over the past 10 years. If this threshold is not met, the CII data element for the particular firm is blank.

5. Science Linkage: This index reflects the number of citations to scientific research literature on the front pages of a company's last 5 years of U.S. patents in a Product Group. High values (>>1) indicate strong linkages to basic science.

6. Technology Cycle Time: This indicates the speed of innovation or technology turnover. It is computed as the median age in years of all U.S. patents referenced on the front pages of a company's last 5 years' patents in a product group. Lower values indicate faster innovation speed.

Not directly included in the supplied data is an important index computed from these data: the Technological Strength Index. This index has been developed by CHI Research and is computed as the product of the number of patent count for the five year period times the CII.

Technological Strength Index = (5-Year Patent Count) * (5-Year CII)

I computed Technological Strength Indexes for all firms for which the CII was included in the patent data.

In addition to acquiring the product group tables listed above from the Tech-Line database, RAND purchased additional data directly from CHI Research for all sample frame firms which are not in the Tech-Line database. The data and indices for these firms were computed by CHI Research in the same fashion as the Tech-Line data.

STRENGTHS AND WEAKNESSES OF USING U.S. PATENT DATA TO MEASURE INNOVATIONS.

Patent data have the virtue of being detailed quantitative data that are readily available. Such data contain citations to other patents on which the new patent relies and to scientific journal

articles on which the patentable invention depends. The time series patent data are comprehensive and represent a standardized way of viewing invention. (Mogee, 1991). Thus, the patent data provide a means for tracing the development of new technologies.

U.S. patent data are also a good proxy for the innovativeness of international firms because most international firms with R&D efforts file for patents in the U.S.[40] Another reason for focusing on U.S. patent data is that they are computerized and contain a great deal of citation information useful in computing a variety of indices. (Narin, Albert, & Smith, 1992).

On the other hand, patent data are by no means an ideal indicator of innovative activity. Patent protection is not sought for all inventive claims. In many cases, firms rely on secrecy. In addition, the number of claims per patent varies from country to country and sector to sector. Tong and Frame have shown for their random sample of firms that U.S. firms make the highest number of claims per patent (13.8), while Japanese firms apply for the lowest (10.1). (Tong & Frame, 1994). They have also shown that patent claims data may be a better indicator of innovative activity than simple patent numerical counts.

More significantly, all inventions for which patents are sought do not become marketed innovations. Studies have shown that the rates for patents which are eventually used in products range from 40 to 60 percent. (Archibugi, 1992). Many are never used, or are obtained solely to block other firms from utilizing any form of important or core technology. However, such patents "still represent a technological capability of the firm." (Archibugi, 1992). And that capability can certainly be brought to bear on firm innovations and further R&D efforts.

A variety of other problems have been noted in the literature as well. Not all patents are of equal technological value. For that

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[40] But one researcher indicates that when making international comparisons, using U.S. patent data only is not accurate for U.S. firms as the "incentives to obtain a patent at home differ from those to obtain a patent abroad." (Mogee, 1991). This may be true, but this research has been limited by time and monetary resources constraining the use of patent data from all available sources.

reason, citations from subsequent patent applications to a firm's existing patents are said to be better indicators of technological capability. (Trajtenberg, 1990). In addition, patent frequency varies greatly from product class to product class, and from country to country. Japanese firms are known to have a higher propensity to patent than firms from other nations. This may be because Japan's patenting system, unlike that of the U.S. and all other Organization of Economic Co-operation and Development (OECD) countries, does not allow several claims to be grouped together on a single patent application. (Archibugi, 1992).

Despite these problems, patent counts are a useful, although abstract and imperfect, indicator of innovative activity. And for purposes of this research, raw patent counts within product groups are sufficiently informative. By including the cumulative impact index, which is based on citations to firm patents, the accuracy of the indicator improves.[41] Hence, the importance of the Technological Strength Index.

ALLIANCE DATA

While the initial research strategy contemplated obtaining alliance data directly from firms by survey, alliance data from the Cooperative Agreements and Technology Indicators (CATI) database and the Securities Data Corporation's (SDC) Joint Venture database became available during the course of the research. These were consolidated to form the most complete picture available of alliance activity in the three research sectors.

CATI alliance data

The Cooperative Agreements and Technological Indicators database was developed by the Maastricht Economic Research Institute on Innovation and Technology (MERIT) at the University of Limberg in the Netherlands. The CATI data bank contains information on almost 10,000

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[41] Weighting patent counts by citation data yields indicators that have been shown to be more accurate than simple patent counts. (Trajtenberg, 1990). But note that the Technological Strength Index is only one way to weight the patent counts by citation data.

cooperative agreements involving some 3500 companies. (Duysters & Hagedoorn, 1993). The data primarily involve agreements entered into between 1979 and 1989, although a percentage (14.8%) are for alliances established before 1979.

Each record in the CATI database is a separate cooperative agreement, and each consists of 112 fields of information. Fifty-five of these fields are sectoral categories and sub-categories. For example, sector categories include computers, industrial automation, microelectronics, software, telecommunications, aircraft, automotive, chemicals, consumer electronics, and defense. The sub-categories of microelectronics include processors, risc-processors, memory chips, custom chips, expansion boards, and transistors.

Each record contains a field for the name of the alliance and number of firms participating in the agreement, and a separate field for the name of each firm participating. Also, each record includes fields for the type of cooperative agreement, the motives for the agreement, the distance from the market where activities are planned, the year established, the year terminated, and general information about the purposes for the alliance. Note that each record contains information common to the two or more firms which are forming the specific alliance. Consequently, this research required backing out the information for each firm, so that the data were arranged on a firm-by-firm basis rather than on an agreement-by-agreement basis.

In selecting specific CATI agreement records for this research, it was important to initially set broad search criteria. My initial choice of search criteria was for any agreement that could possibly be related to aerospace, automotive or semiconductor research, design or manufacturing processes. I included all direct and related CATI categories in which basic research is conducted for any of the three research sectors. These categories included new materials, industrial automation, space technology, electro/magnetics/optics, technical ceramics, powder metallics, fibre composites, technical plastics, metal alloys. Using these criteria, 4018 CATI alliances were selected.

From these data, all agreements involving research and development activities were identified. CATI assigns all agreements to one or more

of 22 types of cooperative activities, of which four are related to joint research: joint research pacts (JRP), joint development agreements (JDA), R&D contract (RDC), and research corporations (RC). All agreements assigned to any one of these categories were included as research cooperative agreements. Of the 4018 agreements, 1463 were research and development agreements.

The data were filtered further by searching for agreements assigned to sectors directly relating to the research sectors: aerospace, automotive and semiconductor. Table 4.2 shows the CATI sectors searched for these more specific sector data.

Table 4.2

CATI sectors initially screened

Research Sector	CATI Sector Name
Aerospace	Aircraft Defense Instrumentation
Automotive	Automotive
Semiconductor	Basic Chips Microelectronics

Finally, the sector specific data were also filtered for research and development agreements.

Thus, the hierarchy of categories for the CATI data was as follows:

1. All CATI agreements: All sector agreements and related agreements. Firm totals for these data include all alliances involving aerospace, automotive, semiconductor, new materials, industrial automation, defense work, etc. Such alliances can be joint ventures, mergers, strategic research alliances, supplier and partner agreements and any other form of agreement. This is the firm cooperative activity writ large.

2. All CATI R&D agreements: A subset of all CATI agreements which involve research and development activities. These data are

all research and development activities across the range of sectors mentioned above.

3. CATI sector agreements: All agreements which are specifically identifiable to the particular sector. These are the aerospace only, automotive only and semiconductor only agreements.

4. CATI sector R&D agreements: All sector agreements that fit one of the four research and development types.

Table 4.3 shows the data distribution.

Table 4.3

Distribution of CATI Agreements

Sector	Total	Total R&D	All Sector	Sector R&D
Aerospace			437	202
Automotive			594	160
Semiconductor			602	323
Totals	4018	1463	1633	685

NOTE: The Total column and Total R&D column count agreements within the product groups plus agreements in new materials, processes, industrial automation, etc. Therefore, these data are aggregate totals. The sector counts are included within these data.

The major limitations of the CATI data are twofold: First, the collection methods are somewhat limited. The process involved graduate students extracting public information from technical journals.[42] Hence, the sources, while perhaps broad, are probably not comprehensive. Moreover, many alliance agreements are not made public by the cooperating companies. Thus, the data represent a sample of the actual agreements and are biased as being only publicly announced alliances. And since the data were collected in Europe there may be a further bias toward agreements involving European firms.

Second, the last year for the CATI data is 1989, about the time the numbers of agreements began to increase dramatically. Thus, the data

[42] These are identified by the CATI researchers as the journals most likely to be read by management and R&D executives in the various industrial sectors. For example, *Aviation Week and Space Technology* in the Aerospace industry.

provide a snapshot, of unknown comprehensiveness, for alliance activity during the 1979-1989 decade.

SDC Alliance Data

Securities Data Corporation began collecting alliance data for its joint venture database in 1989. According to company representatives, SDC gathers its alliance and joint venture data from most technical and business journals and periodicals, as well as from press releases carried on the major wire services. The data begin in 1985 and continue to the present. Thus, the SDC data compensate for the two major weaknesses of the CATI database: they are comprehensive and current.

RAND obtained SDC alliance data for the three research sectors for the years 1985 through 1992.

The SDC database is organized somewhat differently than CATI. Agreements are categorized according to the SIC codes involved in the research and the SIC codes of the participants. To cast the initial scan as broadly as possible, RAND's online SDC searches requested all agreements for which any of the participants fit the SIC codes of the research sectors.

The reports generated by these searches were structured to provide the following information:

- Joint venture name
- Number of participants
- Participant names
- Countries of participant headquarters
- Indicator of whether the alliance crosses international borders
- Date alliance announced in the press
- Status of alliance: deal signed, waiting approval, or terminated
- SIC codes of alliance activities
- Type of transaction: joint manufacturing, joint marketing, joint research and development or supply agreement

Using these data, I classified the agreements by SIC code and whether or not they involved joint research and development. Then I generated a hierarchy of agreements using the SDC data that parallel, but are not identical to, those of the CATI data:

1. All SDC Alliance agreements. This includes all agreements for which any one of the participants has operations within the SIC code areas for the particular sector.

2. All SDC R&D agreements. These include agreements for which joint research and development is at least one activity of the agreement.

3. SIC alliance agreements. These are the total number of alliance agreements involving activities in the specific SIC code. For example, of the 985 agreements in which one or more partner is involved in aerospace activities (3721, 3724, 3728, and 3812 SIC codes),[43] 93 agreements actually involve 3721 (airframe manufacturing) activities.

4. SIC alliance R&D agreements. The joint research and development agreements for each of the SIC codes. Using the example above, 31 of the 985 agreements involve joint research activities in the 3721 SIC code area.

The distribution of the SDC alliance data is illustrated in Table 4.4.

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[43] The description of the SIC codes is found at the beginning of this section

Table 4.4

Distribution of SDC Agreements

Sector	Total SDC Agreements	Total SDC R&D Agreements	Total SIC Agreements	Total SIC R&D Agreements
Aerospace				
3721			93	31
3724			50	10
3728			45	11
3812			60	17
Total[a]	985	273	190	53
Automotive				
3711			170	16
3714			191	19
Total[a]	910	160	336	31
Semiconductor				
3674			580	240
Total	1620	597	580	240

[a]The totals for Aerospace and Automotive SIC agreements and R&D agreements are not the additive sum of the column because some are overlapping agreements. For example, several 3721 agreements also involve 3724 activities and are included in the 3724 row.

FINANCE DATA

The finance data are from the 1993 year-end summary of Moody's Company Data and Moody's International Company Data. The information is derived from publicly filed SEC reporting data. For this research, I obtained the following financial information for U.S. domestic corporations:

1992 Return on Assets

1992 Profit Margin

1990-1992 Gross Operating Revenue (Sales)

1990-1992 Gross Profit

1990-1992 Research and Development Expenses

1990-1992 Net Income

1990-1992 Earnings Per Share

1990-1992 Total Assets

Using these data I computed average sales, profits and net income for the three-year period of 1990-1992.

The same data were obtained for 85 international firms; but, research and development information was generally not available.[44] However, the *Business Week* "R&D Scoreboard" report for 1992 (BWStaff, 1993) does contain 1992 R&D spending for some of the largest international firms in the sample frame.

In addition, 1992 sales, profits, assets, and return on equity information were available for a few additional firms from *Business Week* "Global 1000." (BWStaff, 1993b).

Finally, the 1993 "R&D Scoreboard" provided additional information for U.S. firms from which I was able to compute the average annual R&D spending for the years 1988-1992. The "Scoreboard" includes the 1992 R&D spending, 1992 spending per employee, and average annual spending per employee for the years 1988-1992. To compute the 5-year average annual R&D spending, I assume that the number of employees remains constant over the 5 year period. With that assumption, the calculation is a straightforward ratio computation:

$$\text{1988} - \text{1992 R\&D Spending} =$$
$$\left(\frac{\text{1992 R\&D Spending}}{\text{1992 R\&D Spending per Employee}}\right) \times (\text{Average 1988} - \text{1992 Spending per employee})$$

While the necessary simplifying assumption of constant employee numbers introduces an unknown error component into these data, it is a reasonable assumption to make.

The final source of finance data was the survey questionnaires which asked for 3-year sales, profits and R&D spending. In the few cases where data were unavailable from the Moody's database but provided by survey respondents, I used the financial data from the questionnaires.

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[44] Only a handful of international firms reported research and development figures in the Moody's databases. For example, only two international automobile manufacturers reported R&D data.

Table 4.5 shows the aggregate distribution of the finance data available from these sources.

Table 4.5

Distribution of Available Financial Data:
Number of Firms for which specified data elements are available

Sector	3-year Sales	3-Year Profits	3-year R&D	5-year R&D
Aerospace	89	96	31	54
Automotive	100	116	11	34
Semiconductor	100	104	63	52
Totals	289	316	105	140
US Firms	179	180	89	140
Int'l Firms	110	136	16	0

As is quite clear from this table, R&D data are not readily available for international firms. This, of course, restricts the scope of this analysis, limiting statistical tests involving R&D spending to U.S. firms for which R&D data are available.

QUESTIONNAIRE DATA

Developing the Questionnaire

The initial questionnaire was revised extensively[45] before it was tested. The revised version was sent to R&D executives at 31 firms

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[45] I developed and refined the research questionnaire through several stages. Because none of the alliance data were available at the commencement of this research, I initially drafted a comprehensive questionnaire of 50 questions, 28 pages, and 302 data elements, plus 5 data elements for every alliance and consortia in which the responding firm had participated during the last 10 years. For large firms with multiple alliances, the questionnaire could have run to some 700-1000 data elements. This would have made completion of the questionnaire a Herculean task, and, given the experience of this research, reduced response rates to nearly zero.

In addition to the problems created by the sheer bulk of the questionnaire, the initial draft posed questions that would have been very difficult to answer. For one thing, it asked about the number of firm "innovations" for the prior ten years, including product and process innovations. Also, it requested potentially highly sensitive information about the degree of trust and cooperativeness among specific executives.

selected at random from the sample frame. Follow-up interviews with respondents and several non-responding executives were conducted. During these phone conversations, two factors were stressed that dampened my expectations for a high response rate. First, the most common response was that the executive simply did not have time to fill out *any* questionnaire. One semiconductor executive told me that the two minutes he spent with me on the phone was more time than he had to devote to filling out such an instrument. The second response was that R&D executives are literally inundated with solicitations to respond to mailed surveys. Together, these two factors argued strongly for an even shorter version of the survey instrument. And they warned of the difficulty of obtaining adequate numbers of responses, and the likely necessity for persistent follow-up.

The final version of the survey instrument was even further abbreviated. It is reprinted in Appendix E and consists of 4 pages, 21 questions and 63 data elements. But even this may have been too long as some of the written rejection letters mentioned the lack of time for completing the questionnaire. Moreover, the requested data about sales, R&D spending and profit experience are considered sensitive by many firms, and may have triggered objections at those firms which refused to respond on the basis of company policy.

Survey Process and Follow-Up

The first mailing to the full sample frame occurred during the second week of April, 1994. The cover letter was signed by the research committee members and was designed to trigger interest and create confidence in the nature, intent and confidentiality of the data acquisition project. A copy can be found in Appendix F. Initial responses were disappointing, about 8 percent. In June, 1994, I sent

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Once the initial draft was completed, I refined the instrument in a multi-stage process. First, feedback from dissertation committee members and the RAND Survey Research Group raised clear warning flags about the length. Then a group of aerospace executives with connections to RAND were asked to review a shortened version of the instrument. Responses from the executives underscored the continuing issue of length, and pointed to additional problems with the sensitivity of several questions.

fax transmissions and letters indicating tentative results of the research and soliciting participation from the non-respondents. A copy of this follow-up solicitation can also be found in Appendix F. This follow-up generated substantially more response, particularly from international firms.[46] Table 4.6 indicates the time series of the responses.

Table 4.6

Time Series of Questionnaire Responses

Month	U.S.	International	Total
January	2	1	3
February	-	-	-
March	1	-	1
April	12	-	12
May	9	8	17
June	2	7	9
July	7	5	12
August	9	11	20
September	-	-	-
October	-	2	2
Total	42	34	76

NOTE: Two separate responses were received from one of the companies and one response is counted in two separate sectors. Hence a total of 74 firms responded.

Response Rate and Non-Response Bias

My examination of the CATI and SDC alliance and patent data, which RAND obtained subsequent to mailing the questionnaires, indicated that some 114 firms had neither obtained any patents during the last 5 years, nor engaged in any alliances during the past decade. Many of these firms are automotive and aerospace parts suppliers which assemble, or market, parts made by others. Therefore, because such firms are not involved in alliances or R&D activities and would have no reason to respond to a questionnaire on alliances and innovation, nor have

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[46] As the research design required sensitive information about firm or division sales, profits and R&D spending, substantial effort went into the questionnaire design and follow-up process to motivate participation. The primary incentive was the promise of an eventual report describing the research findings.

information to provide, they were deleted in computing the response rate and analyzing the data.

Of the remaining 393 firms, 75 responses were received from 74 separate firms,[47] fairly evenly split between domestic and international firms, for an overall total response rate of 18.8%. While this rate is substantially below the 40-50% I had anticipated, it compares favorably with the 14% rate obtained by Pekar and Allio in a Booze, Allen & Hamilton survey to 750 CEOs asking about strategic alliances.[48] (Pekar Jr. & Allio, 1994).

Table 4.7 indicates the distribution of the responses. As can be seen, responses for some sectors were significantly higher than others. Within the aerospace industry, major aircraft manufacturers responded at the highest rate for the entire survey. Semiconductor firms responded at the lowest rate. One explanation for the high response rate from aircraft manufacturers may be that since the industry is in the post cold war contraction stage, firm executives may have become interested in cooperative arrangements to spread the risk and preserve the skill base. Since the industry has been highly regulated, very little tradition of cooperation exists, and therefore executives may value possible insights obtained from participation in this research. On the other hand, the semiconductor industry is growing and firms are already quite cooperative. Hence, the motivation to respond may be less. Another factor may have been sponsorship of the research by Project AIR FORCE and the Critical Technologies Institute. Predictably, aerospace contractors would be more likely to respond to the solicitation from Project AIR FORCE than would semiconductor firms.

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[47] Two responses were received from one aerospace firm, one from an important subsidiary and the other from the corporate parent. In another case, one firm tasked their public relations executive to respond, and his response contained only answers to the financial questions. It was not included in the analysis. Finally, one response was counted twice as the firm was included in both the automotive and aerospace sectors.

[48] The Booze, Allen & Hamilton questionnaire was apparently designed to measure the return on alliance investments, the success and failure rate, and the factors influencing alliance outcomes. See Harbison & Pekar Jr., (1993).

Table 4.7

Distribution of Questionnaire Responses

	US	Internat'l	Percent US	Percent Internat'l	Total Percent
Aerospace	22	17	30.1	25.4	27.9
3721	9	9	60.0	33.3	42.9
3724	2	3	25.0	27.3	31.6
3728	3	2	15.8	14.3	15.2
3812	8	3	25.8	20.0	23.9
Automotive	10	9	20.8	10.7	14.4
3711	3	5	25.0	13.5	16.3
3714	7	4	19.4	8.5	13.3
Semiconductor	9	7	10.7	18.9	13.2
3674	9	7	10.7	18.9	13.2
Totals	41	33	20.0%	17.6%	18.8%

NOTE: Of the 33 international responses, 11 were from European countries, 9 were from Japan, and 13 were from other countries.

With this level of response, one expects significant non-response bias in the questionnaire data. As indicated in Table 4.8, the bias was that larger firms responded. One reason might be that larger firms have more personnel available to answer questionnaire solicitations. Another is that large firms are already more involved in alliance activity and executives attribute more value to responding to a questionnaire about alliance activity than do executives of smaller firms which have few, if any, alliances. As the table shows, the responding firms had about twice the mean number of alliances as did firms in the sample frame.

Table 4.8

Large Firms Response Bias

Mean	Sample Frame	Respondents
Number of Employees	12,906	36,964
Total number of R&D cooperative agreements	6.67	11.89

This bias certainly skews the questionnaire data, making the analysis more applicable to larger firms. But this is a favorable bias for policy inferences because national policies are often formed based on the experience of larger firms. In addition, since larger firms are

generally more involved in cooperative alliances, the policy inferences drawn from the results may be more supportable. Finally, if cooperative alliance strategies work well for larger firms, the lessons of the research may be widely generalizable.

ORGANIZING THE ANALYSIS DATABASES

Each data set required special treatment to organize it into a form that could be easily compared and manipulated to perform the analysis and test the research hypotheses. The following explains the steps taken to organize the data for the analysis.

Patent Data

Treatment of the patent data was straightforward.

First, a Foxpro[49] database was created with all of the sample frame firms, their names, ID numbers and their SIC sector. Fields were also created for the patent data from the product group table for the particular sector, and the table of the summary product group, Group 57. Then I merged the data from these two product group tables into the Foxpro patent database. All fields of data provided by CHI Research were included in the research database.

Judgment was required where sample frame firms are subsidiaries of parent companies in the Tech-Line data base. In those cases, I used the total patents of the parent as the total for the sample firm, and the product group data for the parent as the sector patents. My reasoning was that in many cases the sample-frame firm likely performs most research in the particular product group sector for the parent. For example, Harris Semiconductor may perform most semiconductor research for Harris Corporation. A particularly problematic example is Deutsche Aerospace, which is one of many subsidiaries of the conglomerate, Daimler Benz. Assigning all Daimler Benz aircraft patents to Deutsche Aerospace may not be accurate, but it seems reasonable for exploratory research.

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[49] I used Foxpro 2.5 on the Macintosh for all database work in this research. Excel 5.0 was used to manipulate much of the data to organize them so they could be imported into a Foxpro database file.

Finance Data

The financial data from Moody's and the *Business Week* "R&D Scoreboard" were organized initially on an Excel spreadsheet. Three-year average spending, R&D expenses and profits were first computed. Then, using the R&D Scoreboard data, the five-year R&D average spending level was computed using the relationship described above at page 51. The computed information was transferred to a Foxpro database.

Alliance Data

The alliance data presented the major challenge of the data preparation. Alliance data are organized by alliance agreement. Each agreement is a separate record and includes fields for the participant firms and other agreement details. In order to analyze the alliance data, they must be converted from agreement-based data to firm-based data.

The relational database selected for this project does not have the capability of making this conversion directly. Therefore, it was necessary to write Excel macros to perform the conversion operation. The basic process involves the following steps.[50]

The first step was to count the number of alliances in which each firm had participated. The Excel macros read each record and each participant in the records, and then create a new record for each participant referencing the alliance agreement. For example, an agreement with three participants is converted into three new records, one for each participant. Once these new records were created, I sorted the records to create an alphabetical listing of the firms and the agreements in which they participated. A second Excel macro scanned this sorted file and created a summary of the number of agreements in which each firm participated. These summary data were transferred into a Foxpro alliance database.

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[50] Additional preparatory manipulation was required for the SDC data. The SDC data come formatted with each record occupying several lines on an Excel spreadsheet, whereas all of the CATI information is on a single line. Since importing data into the Foxpro database can only be done with data on a single line, it was necessary to convert the SDC data to single line format.

Once all patent, financial and alliance data were entered into separate Foxpro databases, merged data sets were easily created by linking the unique firm identification numbers from two or more separate databases.

Another necessary step was to eliminate the duplicative agreements which appear in both the CATI and SDC database. This was performed by comparing agreements within both databases for the years 1985 to 1989. The duplicates were eliminated from the SDC database. Of the 1030 SDC research agreements, 72 were also in the CATI database.[51] Once the overlapping agreements were identified, Excel macros formatted the alliance data on a firm-by-firm basis and counted the overlapping agreements for each firm. I subtracted this value from the overall SDC agreement count for the sample frame firms.

International Break-down of Alliance Data

For this research, organizing the data to determine the international or domestic characteristics of each agreement was important. Because of its complexity, this phase of the data organization was performed only for research and development agreements. The classification was performed in a multi-step process.

First, the headquarters nationality of each of the companies in the full database of agreements was identified. For the SDC database, this information was readily available as an additional data field. But the CATI data contain no country headquarters information. Therefore each company within the CATI database had to be assigned to a headquarters country. This information was obtained from a variety of sources including the SDC data (where available), a variety of international corporate directories and from the source of the CATI data, MERIT.

The second step was to examine each agreement and determine its international or domestic character, i.e., whether the partners were from the same country, different countries, or different countries all within the European Union. Several Excel macros assisted in this

[51] These numbers of overlapping agreements by sector are as follows: aerospace (17), automotive (26) and semiconductors (29).

process. However, one step of the process required individual examination of each agreement.

In making this determination, I classified an agreement as domestic only if all participating firms are headquartered in the same country. If any one firm in the alliance is headquartered in a country other than that of all the other firms, the agreement is international and either a trading-bloc only agreement, or a cross-trading bloc agreement. If all of the firms are headquartered in different European Union countries, I classified the agreement as a trading-bloc-only agreement. Otherwise, international agreements were classified as a cross-trading-bloc agreements. These include all alliances consisting of firms from different trading blocs: for example, U.S. and Japanese firms, U.S. and European firms, and Japanese and European firms.[52]

The result of this process was a table listing by firm of the number of agreements, number of international agreements, and number of international agreements that cross trading-bloc borders, and the total number of partners, not including the particular firm, in each of these three categories. The information from this table was imported into the Foxpro alliance database.

Table 4.9 illustrates the international distribution of the CATI and SDC research agreements.

[52] In addition, as the research data pre-date the North American Free Trade Agreement (NAFTA), U.S. alliances with Canadian and Mexican firms are classified as cross-trading bloc alliances. Beginning with 1994, they would be classified as trading-bloc alliances.

Table 4.9

International Scope of Research Alliances

	Domestic Only	Trading-Bloc-Only (EU)	Cross-Trading-Bloc International	Total
CATI				
Aerospace	66	38	98	202
Automotive	52	25	83	160
Semiconductor	121	30	172	323
CATI Total	239	93	353	685
SDC				
Aerospace	120	24	129	273
Automotive	73	7	80	160
Semiconduct	304	18	275	597
SDC Total	497	49	484	1030
Total	736	142	837	1715

NOTE: International agreements cross international and, where applicable, European Union trading-bloc boundaries. Trading-bloc-only agreements cross international boundaries but are confined within the European Union. Domestic agreements are those for which all partners are headquartered in the same country.

Analysis Databases

The final step in the data preparation process was to combine all of the data into five analysis databases. These databases contain increasing numbers of data fields but decreasing numbers of cases. The general procedure in creating these databases was to perform a relational database search (in Foxpro), each time increasing the number of sub-databases accessed by the search.

Analysis I Database: Alliances and Patents. The first database consists of all of the firms in the survey sample frame plus 28 additional firms for which semiconductor alliance and patent data were available. These are mostly computer firms and include Hewlett-Packard, IBM, AT&T, and others which perform substantial semiconductor research but which are not SIC 3674 firms.

The database contains all of the CATI and SDC alliance data as well as the patent data from CHI Research. There are 420 firms in the Analysis I database and 55 columns of data.

Analysis II database: Alliances, Patents and Financial Data. The second database consists of those firms in the first database for which financial data are available. It consists of the data elements of the

first analysis database plus the financial data from Moody's. There are 334 firms in the database and 72 data elements.

Analysis III Database: Questionnaire Data. The third analysis database consists entirely of the questionnaire data from the 75 usable questionnaires received. It consists of 75 rows and 70 columns of data.

Analysis IV Database: Alliances, Patents and Questionnaire Data. The fourth database consists of those firms in the Analysis II database from which survey questionnaires were received. It contains all of the Analysis II data for such firms plus their respective questionnaire data. It consists of 74 rows and 102 columns of data. The company for which two questionnaires were received is included only once.

Analysis V Database: Everything. The fifth and final analysis database includes those firms for which all Analysis IV data elements are available, along with all of the financial data for those firms. It consists of 60 firms and 120 columns of information.

SUMMARY

A substantial amount of effort was required to organize the raw patent, alliance, financial and questionnaire data into a format that could be analyzed to test the hypotheses. The patent and financial data involved very little manipulation. However, organizing the alliance data required computer-intensive manipulation to (1) convert the agreement-based data into firm-based data, (2) classify agreements according to their international characteristics and then (3) convert that internationally characterized agreement data to firm-based data. Once the data were imported into separate Foxpro databases, I was able to create five analysis databases. Each contains increasing fields of information but fewer numbers of cases. These databases were then imported into a statistical analysis software package, JMP 3.0, for the analysis described in the next section.

While these data are for the most part aggregated (or averaged) cross-sectional data, the data do permit initial longitudinal analysis as they consist of both early (CATI, 1979-1989) and more recent (SDC 1985-1992) data. It would be possible to organize the data to permit

year-by-year time series analysis. However, for purposes of this research, the data were not further disaggregated.

5. DATA ANALYSIS AND RESULTS - PART I: PRE-EXISTING ALLIANCE AND PATENT DATA AND HYPOTHESES 1 AND 1A

SECTION OVERVIEW

Section 5 is organized to present the statistical analysis and findings of the Hypothesis 1 tests of the pre-existing alliance, patent and financial data. The analysis is shown both for all firms in the dataset, as well as for the U.S. firms alone for which R&D spending data are available. The overall results are presented first in Table 5.1 and the accompanying text. After presenting the results, I outline the remainder of the section.

RESULTS: THE IMPACT OF ALLIANCES ON INNOVATIVE OUTPUT AND PROFITABILITY

The first hypothesis is fully testable with the research data:

> 1. Technology-based firms which pursue an independent research strategy will be less innovative and earn lower returns than firms that engage in multiple R&D alliances and consortia, including international alliances.

The data also provided sufficient information to test an important subsidiary hypothesis, 1A:

> 1A. International alliances will have a greater impact on innovation and earnings than will domestic alliances.

Table 5.1 summarizes the complete regressions testing these hypotheses. The primary dependent variables are firm patent numbers and profits. In addition, a patent productivity dependent variable is tested. This is the total number of patents per 1000 R&D employees. In each of these cases, the predictor variables are the number of the firm's cooperative R&D alliances, its R&D spending (for U.S. firms), and its 3-year sales. The alliances are classified as domestic alliances, European Union-only alliances (which are in effect trading-bloc-only international alliances) and genuinely international alliances (which cross trading-bloc boundaries).

Table 5.1

Summary of Hypothesis 1 Regressions

Dependent Variables	**U.S. Only Firms** Patents	Patent Productivity	Profits	**All Companies U.S. and International** Patents	Profits
Aerospace					
Domestic	..-	-	-	..+	+
EU	NA	NA	NA	+	---
International	+	..+	+++	..+	+++
R&D spending	+	-	--	NA	NA
Sales	..+	++	+++	++	+++
Automotive					
Domestic	..+	..-	--	..+	--
EU	NA	NA	NA	-	+
International	..+	..-	--	++	..-
R&D spending	..+	..+	++	NA	NA
Sales	..+	++	..-	++	+++
Semiconductor					
Domestic	-	..-	--	..+	--
EU	NA	NA	NA	..+	---
Internationl	++	+	++	+++	++
R&D spending	++	--	+++	NA	NA
Sales	++	++	---	++	++
Aggregate: All Sectors					
Domestic	..-	--	+	++	--
EU	NA	NA	NA	..-	---
Internationl	+++	++	++	+++	++
R&D Spending	+++	-	---	NA	NA
Sales	--	++	+++	++	+++

NOTE: Key: (..+/-) Non-significant positive or negative coefficient. (+) Positive coefficient significant at 10 percent level. (++) Positive coefficient significant at 5 percent level. (+++) Positive coefficient significant at 1 percent level. (-,--, ---) Negative coefficients significant at respective 10, 5 and 1 percent levels.

As 5-year R&D data were available only for U.S. firms, the data are analyzed in two sets, one for U.S. firms only, including R&D spending as a controlling variable, and the second without the R&D variable but

including all firms (U.S. and international) in the Analysis II database.

As can be seen from Table 5.1, *patent output is almost uniformly increased by cooperative alliances*, although in some cases the effects are not statistically significant. In a few cases, strictly domestic alliances and those confined within the E.U. have negative impacts. For the regression that aggregates over all sectors and all companies, domestic alliances have a significant positive impact, and E.U. alliances a non-significant negative impact. *Most salient are the impacts of international alliances, which are positive in every case except in the automotive sector, and strongly positive and significant for the aggregate regressions.*

The situation is more complex for profits. The results for each sector are quite distinct. In the "all sectors" aggregate, the profitability of U.S. firms is increased both by domestic and international alliances. The coefficient on international alliances is quite significant. But note that in none of the sectors do domestic alliances have a positive impact.[53] For the "all sectors" aggregate regressions for all companies (U.S. and international), domestic and E.U.-only alliances have a negative impact on profits. Except for the automotive sector, *the influence of international alliances on profits is consistently and significantly positive.*

Patent productivity can be evaluated only for U.S. firms. The data are quite clear that *domestic alliances have a negative influence on patent productivity, but international alliances have a positive impact.* The coefficients are significant for the aggregate case.

As will be shown in the later discussion, causality runs from alliance activity to patents and profits. The showing is important, as the formation of alliances could be, arguably, the result (or by-product) of innovative successes and profitability. If so, alliances would be an interesting phenomenon, rather than an important innovative strategy.

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[53] This may be because of the strong negative impact of R&D spending for the aggregate.

Causality cannot be shown for the R&D spending predictor, however, because the time frame for the 5-year R&D spending data is contemporaneous with that for the 5-year patent data.[54] And the profit data cover the last 3 years of the 1988-1992 5-year period. Hence, the coefficients on the R&D spending variable should be considered to be correlations only.

SECTION 5 ROADMAP

After describing the general analytical strategy, I present the complete analysis of the Hypothesis 1 tests. First, the descriptive statistics are outlined. The variables are described, as are the linear models used in the analysis and correlation tables. Also, the univariate correlations between alliances and patents are shown graphically.

Second, the models are transformed into log-log form and the results of the regressions using patents as the outcome variable presented. Four models are analyzed in Table 5.8. Models 1 and 3 are for all firms; Models 2 and 4 are for U.S. firms alone. The primary independent variable for Models 1 and 2 is the total number of R&D cooperate agreements. For Models 3 and 4, this variable is disaggregated into domestic and international agreements. (And in Model 3, a trading-bloc-only variable is included).

Third, to show the distinct characteristics of the three research sectors, the patent regressions are presented for each sector in Table 5.9 using Model 3. These regressions are contrasted with a similar disaggregation for the U.S. only firms in Table 5.10, which is based on Model 4. The differences among the sectors are further illustrated by the regressions for the technical strength dependent variable in Table 5.11.

Fourth, causation of the alliances on patents is explored. The results are shown in Table 5.12.

[54] One would expect R&D spending in year 1 to result in patents obtained in years 2 through, perhaps as late as, year 10 or more. Hence, R&D spending data should not be expected to be causally connected with contemporaneous patent data, or profitability data since sales of new products generally occur only after patents are applied for.

This entire analysis process is next replicated for the profits dependent variable. First is shown the bivariate correlations and scatter charts. Then, the four models are presented in Table 5.13. In these regressions, the model specifications are improved by the elimination of outliers. Next, the profit regressions by sector are shown in Table 5.14 using Model 3 and the data for all firms. This table includes all cases in the relevant data set. Table 5.15 shows the same sector specific regressions with corrections for outliers. In Table 5.16, these are contrasted with the Model 4 sector regressions for the U.S. firms.

As with the patent analysis, causation is tested for the impact of alliances on profits. The results for all cases are shown in Table 5.17. Table 5.18 shows the same analysis after elimination of outliers.

The section concludes with two tangential analyses. First, the patent productivity for U.S. firms is analyzed and the results presented in Table 5.19. Figure 5.4 illustrates graphically the productivity gains correlated with multiple firm alliances.

Second, the results of follow-up interviews with executives is presented. The primary suggested explanation of these interviews, defensive patenting, is then tested. The results are shown in Table 5.20.

GENERAL ANALYTICAL STRATEGY

Straight-forward statistical analysis using linear modeling and multiple regressions was employed to analyze the data. Several perspectives on the data are presented: first, the entire dataset; second, U.S.-only data, which includes R&D spending information not available for international firms; and third, sector disaggregated data for both the entire data set and the U.S.-only data.

Transformations are necessary to improve the model specifications and reliability. For the patent performance models, I use natural logarithm transformations. For the profitability models, log transformations are not available since many of the firms have large losses, i.e., negative profit values. Therefore, to improve the

specifications of the profitability regressions, I eliminate outlying data observations.

Outliers are best eliminated by examining the studentized residuals of the regression data, and eliminating those observations with high values, over 2.0. (Draper, 1991; Weisberg, 1985). A studentized residual is a measure of the divergence of a point observation without the influence of the point itself. In other words, it is the residual standard deviation from the regression line with the observation itself temporarily set aside. Eliminating observations with studentized residuals over 2.0 removes the influence of cases with unusual errors which have greater than normal impact on the regression.

THE VARIABLES

Dependent Variables

Three dependent variables are used to test these hypotheses. Two relate to innovation and one to profitability.

SECPATS (sector patents). The number of patents within the applicable product group or sector is the primary innovation output variable. As discussed above, patents are a reasonable, if imperfect, proxy for innovation.

TSSECTOR (technical strength in the sector). The second innovation variable is technical strength. This is computed by multiplying the number of sector patents by each firm's cumulative impact index (CII), the latter being a measure of the relative impact or influence a firm's patents have had on subsequent patents in the sector for the past five years. As described above, the CII is a normalized index of the citations to a firms' patents, relative to all citations to all sector patents.

AVNI (average net income (profits) (1990-1992)). The financial performance variable from Moody's Company Data is the average firm profits over three fiscal years, 1990-1992. This variable, along with all other financial sales, expenses and profits data, is stated in millions of dollars ($1M).

Independent variables

TOTRDAG (total R&D agreements). These are the total number of R&D agreements from both the CATI and SDC databases related to the industrial sector of the sample firms. The variable does not include R&D agreements in the CATI database which are not directly related to the sector activities. The excluded CATI agreements are those involving new materials research, automation research and the like.

AV3YRSALES (average 3-year sales). The average firm sales for the three final years of the research time span, 1990-1992.

AVGRD8892 (average R&D expenses for 1988-1992). This 5-year average R&D spending variable is computed as explained above on page 51 from information found on the 1993 *Business Week* "R&D Scoreboard." Thus, the data are limited to those U.S. firms in the sample frame that were also included in the "Scoreboard."

ALLDOMRD (all domestic R&D agreements). These are the research and development agreements into which a firm has entered with firms of the same headquarters' nationality. It includes all CATI and SDC domestic agreements.

ALLTBORD (all trading-bloc-only R&D agreements). This measures the number of research and development agreements formed by European firms involving firms from other countries within the European Union. The variable includes both CATI and SDC agreements.

ALLXTBRD (all cross-trading-bloc R&D agreements). These are all non-domestic research agreements that cross trading blocs. In other words, these are international research agreements, not confined within the European Union. Like the other alliance variables, it includes both CATI and SDC agreements. If any one firm which is party to the agreement is from a non-domestic and non-trading-bloc country, the agreement is classified as a cross-trading-bloc agreement. For example, an agreement among a German, British, and Italian firm is a trading-bloc-only agreement. But if a fourth firm, a Japanese or American, firm is also party to the agreement, the agreement is classified as a cross-trading-bloc agreement. The category thus includes agreements of U.S. and Japanese firms, Japanese and European Firms and U.S. and European firms.

E_r is the model error term. This is the residual error for each observation in the tested data set. The residual error is the difference between each observation's dependent variable value and the least-squares fitted linear regression value for the independent variables of the observation. Linear regressions assume normally distributed residual errors.

Reasons for Choice of Raw Variables

Prior studies have used a variety of density normalization approaches for creating dependent and independent variables. For example, as one dependent variable, Hagedoorn and Schakenraad used a patent intensity variable, computed by dividing the number of patents by the average firm sales. (Hagedoorn & Schakenraad, 1994). They also weight the number of alliances, an independent variable, by the average sales. Rather than following this procedure, I chose to use raw patent and alliance data for the analysis, and controlled for firm size by the inclusion of firm size as an independent variable in the multiple regressions. For multiple regression analysis, this may be a more accurate approach as the outputs (patents and profits), may be affected by an explicitly recognized size variable. Moreover, a density variable measures a concept closely related to, but distinct from, the actual count of patents or profits.

THE MODELS

The models are linear equations relating the impact of cooperative R&D alliances on patent output and profitability. The first test is of the innovativeness of the firms as measured by sector patent output and technological strength indicators.

(1) Sector patents $= a_o + b_1\text{TOTRDAG} + b_2\text{AV3YRSALES} + e_r$

(2) Sector patents $= a_o + b_1\text{TOTRDAA} + b_2\text{AV3YRSALESS} + b_3\text{AVRD8892} + e_r$

The Total R&D agreement variable can be disaggregated into separate domestic, non-domestic trading-bloc, and cross-trading-bloc agreements. In this way, the relative impact of each type of agreement can be tested.

(3)

$$\text{Sector patents} = a_o + b_{11}\text{ALLDOMRD} + b_{12}\text{ALLTBORD} + b_{13}\text{AllXTBRD} + b_2\text{AV3YRSALES} + e_r$$

(4)

$$\text{Sector patents} = a_o + b_{11}\text{ALLDOMRD} + b_{12}\text{ALLTBORD} + b_{13}\text{AllXTBRD} + b_2\text{AV3YRSALES} + b_3\text{AVRD8892} + e_r$$

The same equations are utilized for testing the technical strength and profits variables by substituting the technical strength (TSSector) and 3-year average profits (AVNI) variables for sector patents.

To disprove Hypothesis 1, the signs on the b_1 coefficients must be less than zero: $b_1<0$. A positive sign and statistically significant coefficient on the b_1 variables would support the hypothesis.

The subsidiary hypothesis would be disproved if $b_{11}>b_{13}$ or if $b_{13}<0$. If $b_{13}>b_{11}$ and $b_{13}>0$, the hypothesis would be supported.

DESCRIPTIVE STATISTICS

As no questionnaire data are involved in testing this hypothesis, data from the Analysis II database are used. This provides 335 observations, more than sufficient for statistically valid results.[55] However, when the R&D spending variable is included, the number of observations drops to 148 U.S. firms.

Table 5.2 shows the correlations, means and standard deviations for the aggregated version of the analysis variables.

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[55] For the regression models, the sample size is reduced to 302 observations for which sales information is available.

Table 5.2

Descriptive Statistics for full Analysis-II data set

Variable	Mean	Median	75% quartile	Maximum Value	SD
SECPATS	79.9	6.0	30.0	2144	266.0
TSSECTOR	96.2	0.0	30.2	2680	342.1
AVNI	88.8	9.5	60.1	4059	418.5
TOTRDAG	4.56	0.00	3.0	85	11.3
ALLDOMRD	2.1	0.00	1.0	62	6.1
ALLTBORD	.37	0.00	0.0	19	1.76
ALLXTBRD	2.11	0.00	1.0	41	5.6
AV3YRSALE	5600	697	3865	95356	12692
AVGRD8892	207.9	15.0	84.6	5350	680.5

NOTE: AVNI, AVGRD8892 and AV3YrSales are in $1M. 90 percent of the firms have no ALLTBORDs.

As is clear from the summary statistics, over 50 percent of the firms in the analysis database have no cooperative agreements. Thus, the alliance data are heavily skewed. Moreover, the patent and technical strength data are similarly skewed. This strongly suggests that the alliance and patent data should be evaluated by transforming the variables to logarithmic form. This improves the normality of the distributions of the variables, which makes the distribution of least squares errors more normal, and therefore more consistent with the linear regression assumptions.[56]

As one would expect, the data are not uniform over the three sectors. The substantial differences among the sectors are illustrated in Table 5.3. This suggests that disaggregated analysis may be more meaningful for firms and industries.

[56] See Appendix A for a description of these assumptions.

Table 5.3

Summary Descriptive Statistics by Sector for Full Analysis-II Data set

	Aerospace		Automotive		Semiconductor	
	Mean	Median	Mean	Median	Mean	Median
SECPATS	30.8	4.0	31.4	2.0	167.3	12.5
TSSECTOR	28.0	0.0	37.0	0.0	209.7	8.9
AVNI	108.2	14.7	74.6	13.3	86.8	5.1
TOTRDAG	3.0	0.0	2.64	0.0	7.7	1.0
ALLDOMRD	1.06	1.0[a]	1.2	1.0[a]	3.7	0.0[a]
ALLTBORD	.43	0.0[a]	.38	0.0[a]	.32	0.0[a]
ALLXTBRD	1.46	1.0[a]	1.06	1.0[a]	3.7	3.0[a]
AV3YrSales	4148	1357	7399	1316	5250	220
AVGRD8892	138.4	17.6	300.6	8.0	217.7	16.5

NOTE: AVNI, AVGRD8892 and AV3YrSales are in $1M.
[a]The median figures for the domestic, trading-bloc and cross-trading bloc agreement variables are for the 75% quartile, as all 50% median values are zero.

As is evident from comparing this table with Table 5.2, the average semiconductor firm engages in more than twice the number of cooperative research agreements as do aerospace and automotive firms. The somewhat older aerospace and automotive sectors are similar in terms of the number of patents firms obtain and alliances they form. Median sales for these two sectors are almost identical as well. Mean R&D expenses of aerospace firms are almost double those of automotive firms. But they are comparable to those for semiconductor firms.

Correlations

Table 5.4 presents the aggregate correlations for the above model equations.

Table 5.4

Correlations for entire Analysis-II data set

	SECPAT	TSSECT	AVNI	TOTRD	AllDom	AllTBO	AllXTB	SALES
SECPATS	1.0	.98	.27	.71	.50	.29	.79	.57
TSSECTOR	.98	1.0	.29	.68	.51	.17	.75	.56
AVNI	.27	.29	1.0	.22	.12	-.02	.31	.47
TOTRDAG	.71	.68	.22	1.0	.90	.34	.93	.55
AllDOMRD	.50	.51	.12	.90	1.0	.04	.70	.41
AllTBORD	.29	.17	-.02	.34	.04	1.0	.34	.27
AllXTBRD	.79	.75	.31	.93	.70	.34	1.0	.58
AV3YRSALES	.57	.56	.47	.55	.41	.27	.58	1.0

NOTE: The dependent variables are bracketed from the independent variables.

The correlation chart is shown for the entire data set of 335 firms. If the research and development expenses variable were included, the number of observations in the set would be reduced to the 148 U.S. firms for which R&D *and* sales data are available. Tables 5.5, 5.6, and 5.7 are based on data for 148 U.S. firms. The correlation table, Table 5.7, shows that there is significant correlation between the average sales variable and the research and development expenses variable. In addition, the cross-trading-bloc variable is highly correlated with the domestic research agreement variable.

Table 5.5

Descriptive Statistics for the U.S. firms with R&D Data in the Analysis-II data set

Variable	Mean	Median	Maximum Value	SD
SECPATS	76.9	6.0	1525	240.1
TSSECTOR	102.7	0.0	2332	354.2
AVNI	73.0	8.6	4059	509.9
TOTRDAG	5.32	.5	85	13.0
ALLDOMRD	3.15	0.0	62	8.1
ALLXTBRD	2.16	0.0	39	5.4
AV3YRSALES	4310.8	348	95356	12468
AVGRD8892	209.3	15.1	5350	682.6

NOTE: AVNI, AVGRD8892 and AV3YrSales are in $1M.

Table 5.6

Summary Descriptive Statistics by Sector for U.S. Firms with R&D Data in the Analysis-II Data Set

	Aerospace		Automotive		Semiconductor	
	Mean	Median	Mean	Median	Mean	Median
SECPATS	30.7	3.0	23.4	1.0	147.0	17.0
TSSECTOR	30.0	0.0	24.6	0.0	209.3	24.3
AVNI	187.1	19.8	-99.1	4.2	65.0	6.5
TOTRDAG	3.24	0.0	3.0	0.0	8.43	1.0
ALLDOMRD	1.61	2.0[a]	1.88	1.0[a]	5.20	5.5[a]
ALLXTBRD	1.61	1.0[a]	1.12	0.5[a]	3.20	3.0[a]
AV3YRSALES	4600	653	5750	528	3300	197
AVGRD8892	138.4	17.6	309.6	8.1	217.7	16.5
Number Cases	54		33		61	

NOTE: AVNI, AVGRD8892 and AV3YrSales are in $1M.

[a] The median figures for the domestic, and cross-trading-bloc agreement variables are for the 75% quartile, as all 50% median values are zero.

Table 5.7

Correlations for US Firms with R&D Data in Analysis-II Data Set

	SECPAT	TSSECT	AVNI	TOTRD	AllDOM	AllXTB	SALES	AVRD8892
SECPATS	1.0	.99	.18	.68	.63	.66	.51	.58
TSSECTOR	.99	1.0	.18	.61	.57	.60	.49	.55
AVNI	.18	.19	1.0	.16	.08	.27	.27	-.15
TOTRDAG	.68	.61	.16	1.0	.97	.94	.51	.54
AllDOMRD	.63	.58	.08	.97	1.0	.84	.48	.55
AllXTBRD	.66	.60	.27	.94	.84	1.0	.50	.47
AV3YRSALES	.51	.49	.27	.51	.48	.50	1.0	.81
AVRD8892	.58	.55	-.15	.54	.55	.47	.81	1.0

NOTE: The dependent variables are bracketed from the independent variables.

As can be seen in Table 5.4, the cross-trading bloc agreements variable, ALLXTBRD, is most strongly correlated with the dependent variables: SECPATS, TSSECTOR and AVNI. The domestic agreements variable, ALLDOMRD, is highly correlated with the cross-trading bloc variable (.70), but neither is highly correlated with the trading-bloc-only variable. And the sales variable, used for controlling for size effects, is only moderately correlated with the alliance variables.

From Table 5.7, it is clear that truncating the data set to the 148 U.S. firms, including the R&D variable and deleting the ALLTBORD variable, increases the correlation between the domestic and cross-trading bloc variables to .84, suggesting potential multicollinearity problems in the linear regressions.

ANALYTICAL TESTS OF HYPOTHESIS 1 AND 1A

Patent Regressions and Scatter Charts

The untransformed regressions of the aggregate patent data generally show support for Hypotheses 1 and 1A. However, the signs and magnitudes of the alliance coefficients provide a unique view of the relative importance of international, domestic and trading-bloc only agreements. Before summarizing and discussing the regressions, I illustrate the bivariate correlations of the dependent variable and the two important independent variables.

The following graphs shows the one-dimensional correlations of the total R&D agreement variable (Figure 5.1) and the cross-trading bloc variable (Figure 5.2) on patent output.

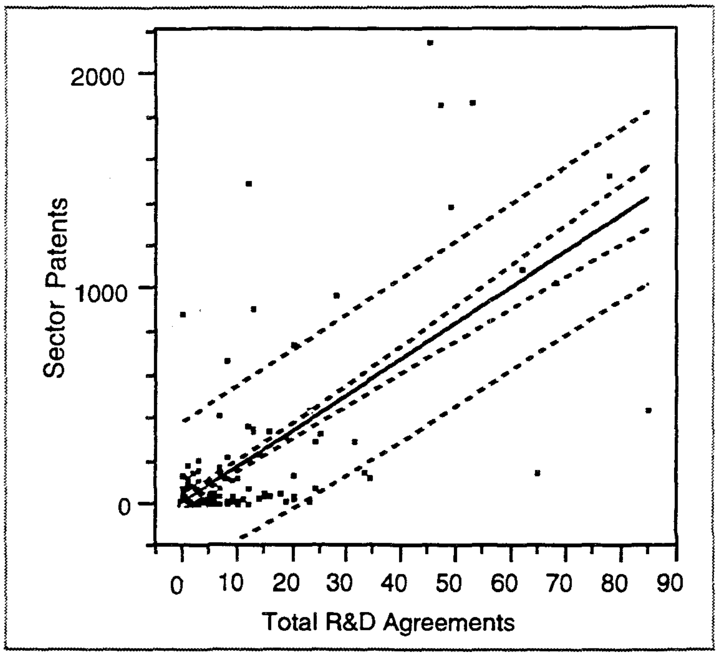

Figure 5.1—Correlation of sector patents and total research and development agreements

NOTE: R^2 is .50, the number of observations is 335, the total F ratio is 330.3, the coefficient on Total R&D Agreements is 16.6 with a standard error of .914. It is significant at the .0001 level. The solid line is the least squares fit, the inner dotted lines are the confidence interval for the fitted line. The outer dotted lines are the confidence interval for the data.

These two figures clearly show the strong correlation between patent output and cooperative research agreements, and especially between patent output and international cross-trading bloc agreements.

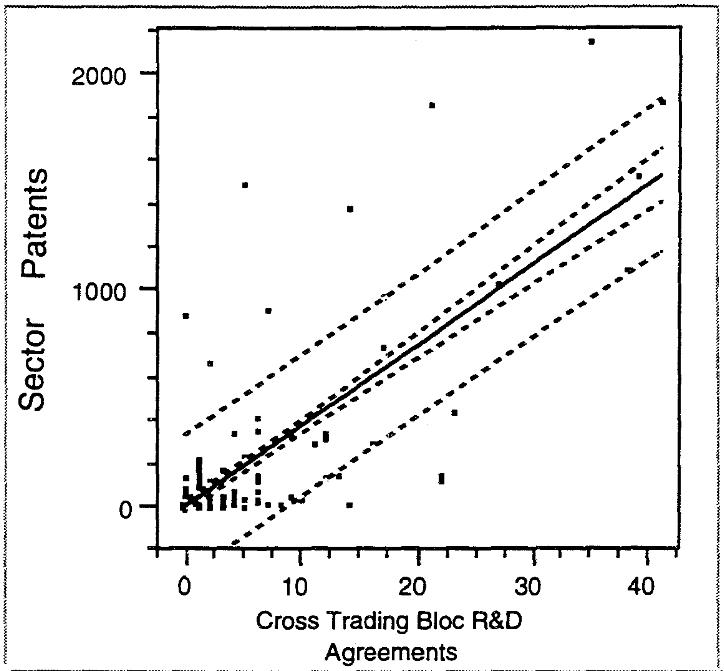

Figure 5.2—Correlation of sector patents and cross-trading bloc (international) research and development agreements

NOTE: R^2 is .62, the number of observations is 335, the total F ratio is 529.5, the coefficient on the Cross-trading bloc R&D agreements is 37.3 with a standard error of 1.62. It is significant at the .0001 level. The solid line is the least squares fit, the inner dotted lines are the confidence interval for the fitted line. The outer dotted lines are the confidence interval for the data.

Transformed Models

As further explained in Appendix A, the variables for this analysis should be converted to logarithms. The logarithm transformation eliminates most of the non-normality in the patent and alliance variables, and regression residuals. It also improves the uniformity of the variance of the residuals.[57] Together, these changes improve the

[57] This is the homskedasticity assumption of common variance. Violation of the assumption is known as heteroskedasticity.

linear specification of the models. By transforming the variables, the linear models are written in the following form:

$$\ln(Y_i) = b_o + b_1 \ln(X_i) + u_i$$

This is equivalent to the following untransformed model:

$$Y_i = e^{b_o} X_i^{b_1} e^{u_i}$$

Obviously, the regression coefficients of such a model, b_0, b_1, etc., must be interpreted differently than those of untransformed linear models. For transformed models, two key parameters are important. First, the marginal, or partial derivative, $\frac{\partial y}{\partial x}$, is the change in the function Y, for a unit change in x. The marginal of the transformed models is equal to: $b_j \frac{\overline{Y}}{\overline{X}}$. (In the linear model, the marginal is simply the regression coefficient b_j).

The second important parameter is the elasticity: the percent change in Y over a 1 percent change in X. For transformed models, the elasticity is simply equal to b_j, the regression coefficient.

The full models for analyzing the transformed data are the following:

(1) $\ln(\text{SECPATS}) = a_o + b_1\ln(\text{TotRDAg}) + b_2\ln(\text{Av3yrSales}) + e_r$

(2)
$$\ln(\text{SECPATS}) = a_o + b_1\ln(\text{TotRDAg}) + b_2\ln(\text{Av3yrSales}) + b_3\ln(\text{AvRD8892}) + e_r$$

(3)
$$\ln(\text{SECPATS}) = a_o + b_{11}\ln(\text{AllDOMRD}) + b_{12}\ln(\text{ALLTBORD}) + b_{13}\ln(\text{AllXTBRD}) + b_2\ln(\text{Av3yrSales}) + e_r$$

(4)
$$\ln(\text{SECPATS}) = a_o + b_{11}\ln(\text{AllDOMRD}) + b_{12}\ln(\text{ALLTBORD}) + b_{13}\ln(\text{AllXTBRD}) + b_2\ln(\text{Av3yrSales}) + b_3\ln(\text{AVRD8892}) + e_r$$

As above, for further analysis the models can be modified by substituting the natural log of the technical strength variable and the average net income variable for the sector patent variable.

Sector Patent Regressions Using Transformed Variables

Table 5.8 shows the four regressions using transformed variables. For the primary independent variables, I show the marginals in square brackets [ ]. These are computed with the mean values for sector patents and the relevant independent variable, using the formula $b_j \frac{\overline{Y}}{\overline{X}}$.

Again, the marginals are the change in the model value (Y), for each unit change in the relevant independent variable. Since each transformed variable is computed as the natural log of 1+ the raw variable,[58] I also add one (+1) to the mean of Y and X to compute the marginals.

The regressions in Table 5.8 show clearly that research and development agreements have a strong positive, and highly significant, impact on patent output in both Models 1 and 2. In these models, the b_1 coefficients are positive, supporting Hypothesis 1. Moreover, Models 3 and 4 show that research agreements which cross trading-bloc boundaries have the strongest positive impact. In these models the b_{13} coefficients are greater than zero and more than the b_{11} coefficients, supporting Hypothesis 1A.

In Model 3, domestic agreements also have a positive and significant impact on the dependent variable, but only with half the magnitude of the cross-trading-bloc coefficient. Trading-bloc-only agreements have virtually no impact. Although the sign on the AllTBORD coefficient is negative, the p value is very high (.85). In Model 4, evaluated using the U.S. 148 firms, domestic agreements have a negative, but non-significant impact, while cross-trading-bloc agreements have a strong positive and significant impact.

Also of interest is the relative magnitude of the coefficient for R&D expenses. The coefficient is positive and significant at the .01

58 To avoid losing observations in the regression for which alliance or patent data are zero.

percent level. One might think that R&D spending and alliance coefficients could be directly compared to determine their relative

Table 5.8

Sector Patents Log-Log Regressions

Dependent Variable Natural Log Sector Patents	Model (1)	Model (2)	Model (3)	Model(4)
R^2	.57	.64	.58	.66
Adjusted R^2	.57	.63	.58	.65
Mean response	2.25	2.23	2.25	2.23
Observations	299	146	299	146
Intercept	-.236 (.253)	.675 (.471)	-.148 (.254)	.958 (.468)**
LNTOTRDAG Log of total R&D agreements	.97**** (.078) [14.1]	.433** (.140) [6.3]		
LNAV3YRSALES Log average 3-year sales	.256*** (.041)	-.167 (.114)	.248**** (.041)	-.233** (.111)
LNAVRD8892 Log 5-year average annual R&D spending (1988-92)		.707**** (.133) [.274]		.778**** (.126) [.301]
LNALLDOMRD Log domestic R&D agreements			.446*** (.134) [11.6]	-.122 (.182) [-3.2]
LNAllTBORD Log trading-bloc only agreements			-.033[1] (.186) [-1.95]	
LNAllXTBRD Log cross-trading bloc agreements			.904**** (.141) [23.5]	.778*** (.126) [20.2]

NOTE: Standard errors are in parentheses. Significance indicated by the asterisks: (*) p<.1, (**) p<.05, (***) p<.001, (****) p<.0001. Model 4 has no entry for ALLTBORD as the firms in the sample are only U.S. firms which have no such trading block agreements. Transformed marginals are shown in brackets [].

[a]The p value is .85. Therefore, the trading-bloc-only agreements have virtually no impact on the sector patents.

contributions. But that should only be done with caution, as the two independent variables are not contemporaneous. R&D expenses cover 1988-1992, the same period as the dependent patents variable. But the alliance totals cover the full 1979-1992 time frame. Hence a direct comparison is not feasible. Moreover, these data have not been prepared to test the relative contributions from time series predictors.[59] Thus, it is not possible to tell what the relative causal sequences and impacts are.

Nevertheless, looking at Model 2, the relative size of the coefficients indicate that *each R&D agreement has about the same effect on the patent outcome as $23 million of R&D spending.* And Model 4 indicates that *the innovative effect of one international research and development agreement for a U.S. firm is comparable to that of $67 million in research spending!* Time series analysis would be required to actually test the relative equivalence of these predictors.

Comparison of this table with Table A.1 in Appendix A, which shows the regressions for the untransformed variables, indicates that the transformation slightly weakened the correlations. For example, in Model 3, the marginal impact of ALLXTBRD on SECPATS is 36.0 for the untransformed version and 23.5 for the log version. Both, however, are significant at the .0001 level. In Model 4, the marginal increased from 19.6 to 20.2, but the significance fell from the .0001 level to the .001 level. In Model 2, the marginal on TOTRDAG fell from 9.4 to 6.3, and the significance decreased as well, from the .0001 level to the .05 level. On the other hand, in Model 1, the marginal on TOTRDAG increased from 13.3 to 14.1.

Another problem involves the AllDOMRD variable. In the raw data analysis of Model 3, this variable was negative and significant at the .1 level. In the transformed Model 3, ALLDOMRD is positive and significant at the .001 level. Similarly in Model 4, the ALLDOMRD marginal went from a positive 2.6 to a negative 3.2, although neither is significant.

[59] For time series analysis, the alliance, patent, R&D spending and profit data would need to be formatted on a year-by-year basis.

Nevertheless, the major characteristics of the models remain constant across the transformation. *Aggregate research agreements have a significant and positive impact on patent output in both. Moreover, international research agreements have a stronger impact than domestic agreements.* In the regressions on the transformed variables, *cross-trading-bloc agreements are twice as influential on patent output as are domestic agreements.* On the other hand, trading-bloc-only agreements in the transformed regressions have virtually no impact on patent output.

Patent Regressions by Sector

As the distributions of alliances and patents vary substantially across the three research sectors, a more accurate picture may be seen by disaggregating the data into their respective sectors. The disaggregation in Table 5.9 is based on Model 3, which includes all international firms and controls for size, but not for R&D expenses.

The disaggregation makes clear that the impact of alliances varies from sector to sector. While the impact of domestic alliances is consistently positive, but not significant, across the three sectors, the impact of trading-bloc-only and cross-trading-bloc alliances varies. *European trading-bloc-only alliances are strongly positive in the aerospace sector, and equally negative in the automotive sector,* while in the semiconductor sector such alliances have a slight but almost insignificant positive impact. In contrast, cross-trading-bloc alliances are strongly positive and highly significant in the semiconductor and automotive sectors, but only mildly positive and not significant in aerospace.

Viewing the results by sector may provide clues of the impact of structural competitive, innovative and regulatory environments on the relationship between alliances and performance. Among the three sectors, the heavily regulated and subsidized aerospace sector has derived the least benefit for innovation from cross-trading-bloc alliances, but more from domestic alliances, and much more from trading-bloc-only alliances. In the globally competitive automotive sector, the cross-trading-bloc alliances are very influential, while European

Table 5.9

All Sector Patents Analyzed by Sector Using Log Transformed Model 3

Dependent Variable LNSECPATS	Aerospace	Automotive	Semiconductor
R^2	.55	.60	.72
Adjusted R^2	.53	.58	.71
Mean response	1.89	1.83	2.94
Observations	90	99	110
Intercept	-1.78**	-.892	-.223
	(.616)	(.585)	(.229)
LNAllDOMRD	.447	.355	.243
Log domestic	(.284)	(.299)	(.155)
R&D	[6.90]	[5.23]	[8.70]
agreements			
LNAllTBORD	.683*	-.519*	.046[a]
Log trading-	(.309)	(.288)	(.294)
bloc R&D	[15.2]	[-23.2]	[5.9]
agreements			
LNAllXTBRD	.175	1.10***	.720****
Log cross-	(.284)	(.301)	(.169)
trading-bloc	[3.67]	[17.3]	[25.8]
agreements			
LNAV3YRSALES	.471****	.302***	.410****
Log average	(.096)	(.089)	(.055)
3-year sales			

NOTE: Standard errors are in parentheses. Significance indicated by the asterisks: (*) p<.1, (**) p<.05, (***) p<.001, (****) p<.0001. Transformed marginals are shown in brackets [ ].

[a] The p value is .875. Therefore, the trading-bloc-only agreements have virtually no impact on the semiconductor sector patents.

trading-bloc-only alliances have had a strong negative influence. For the rapidly innovating semiconductor sector, the European trading-bloc alliances have been only mildly helpful, domestic alliances have had a positive impact and cross-trading-bloc alliances have had a very strong positive impact on patent output.

Thus, it appears that the more an industry is growing (e.g., the semiconductor sector) the more that international alliances result in innovation benefits. Fierce competition (e.g., the European automotive sector) or forced cooperation (e.g., the European trading-bloc

semiconductor alliances) may reduce the degree of trust and sharing required for research innovations.[60]

When R&D spending is included as a predictor and the sample frame limited to U.S. firms, the picture changes somewhat. Table 5.10 shows the disaggregated regressions for U.S. firms, with the added R&D spending variable, and without the trading-bloc-only variable.

Table 5.10

U.S. Sector Patents Analyzed by Sector Using Log Transformed Model 4

Dependent Variable LNSECPATS	Aerospace	Automotive	Semiconductor
R^2	.65	.79	.72
Adjusted R^2	.62	.77	.70
Mean response	1.77	1.43	3.08
Observations	54	32	61
Intercept	-1.2 (1.11)	-1.36 (1.12)	-.840 (.645)
LNAllDOMRD Log domestic R&D agreements	-.491 (.410) [-5.96]	.362 (.436) [3.07]	-.361* (.203) [-8.62]
LNALLXTBRD Log cross-trading bloc agreements	.668* (.371) [8.11]	.253 (.491) [2.91]	.582** (.210) [20.5]
LNAV3YRSALES Log average 3-year sales	.209 (.256) [.0014]	.251 (.220) [.0011]	.401** (.184) [.018]
LNAVRD8892 Log average 5-year R&D spending 1988-92	.648* (.128) [.145]	.316 (.210) [.025]	.445** (.191) [.301]

NOTE: Standard errors are in parentheses. Significance indicated by the asterisks: (*) p<.1, (**) p<.05, (***) p<.001, (****) p<.0001. Transformed marginals are computed using the mean Y and X for the data included in each sector and are shown within the brackets [ ].

[60] Further research analyzing the impact of such competitive and structural factors on the effectiveness of alliances on innovation, would be useful.

Comparing the disaggregation for U.S. firms alone in Table 5.10 with that for the entire data set, Table 5.9, provides several insights. In considering the similarities and differences it is important to keep in mind that the U.S. disaggregations in Table 5.10 include the effect of R&D spending.

In the aerospace sector, the coefficient for domestic alliances for the entire dataset is positive and non-significant, but negative and non-significant for the U.S.-only regression. International agreements have a slight positive impact for the entire data set, but for the U.S. firms alone they have more than twice the effect and are significant. This significant effect can be attributed to several possible factors. Interviewed executives[61] stressed the importance of defensive patenting, or seeking patents to protect technology from the opportunism of potential partners. Executives also noted that in the aerospace market, the customer is usually a government. Partnerships are needed to provide access to markets to realize profitable sales. And indeed such restricted access means that alliances may be the primary channel of innovative ideas from international government-dominated markets.

In the automotive sector, the relative advantage of international agreements over domestic agreements is moderated and reversed. For U.S. automotive firms, domestic alliances have a slightly stronger positive impact on patents than international alliances. But neither coefficient is statistically significant. The non-significance of the cross-trading bloc alliances for U.S. firms alone is curious. The interviews did not yield insights explaining this pattern. However, it may be due to the perceived take-over of U.S. markets by foreign competitors dampening the willingness of U.S. firms to engage in genuine R&D cooperation with invaders. Thus, the competitive nature of the sector may affect the impact of alliances.

In contrast, in the semiconductor sector, the experience of the entire data set is accentuated for the U.S. firms. For U.S. firms, not only do domestic agreements have weaker impact than international

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[61] See the full text of the fax interview comments in Appendix G.

agreements, they have a negative impact (significant at the 10 percent level), while international agreements remain strongly positive and significant at the 1% level. Interviewed executives commented that the domestic competitiveness of U.S. semiconductor firms may inhibit the innovative productivity of their alliance relationships.[62] On the other hand, for Japanese partners patent production is very important because patent awards are one of the few ways Japanese engineers can distinguish themselves. Moreover, Japanese semiconductor companies develop their reputations based on patent production. Hence, international R&D agreements with Japanese semiconductor firms could be expected to generate more patents.

Moreover, the semiconductor sector is growing rapidly throughout the world. This changes the competitive perception and makes R&D cooperation with international partners mutually beneficial.

Also note that a comparison of the marginals of the R&D spending and cross-trading-bloc variables, in the semiconductor sector, indicates that about $68.1 million in additional R&D spending is correlated with one extra cross-trading bloc agreement.[63] Finally, notice the relative strength of the R&D marginals across the sectors. Semiconductor R&D spending has the strongest correlation with patent output, while R&D spending in the automotive sector has the lowest. This is an indication of the relative degree that R&D activities in each sector yield patentable innovations.

Technical Strength Regressions by Sector

Sector patents are highly correlated with technical strength (.98) because technical strength is the product of sector patents and the cumulative impact index. Therefore, the aggregate technical strength analysis tracks the analysis of sector patents very closely and need not

[62] While the market is growing in the U.S., the perception may be that the size of the pie is relatively fixed. Since many semiconductor companies are headquartered in the U.S., this perception may lead to increased perceived competitiveness, and less effective cooperation, in domestic markets.

[63] This is computed by dividing the marginal for ALLXTBRD by that for AVRD8892. (20.5 / .301). But note the cautionary time series causality issue discussed above.

be repeated here in its entirety. However, the following shows the disaggregated analysis for technical strength using Model 3.

Table 5.11

Technical Strength Analyzed by Sector Using Model 3

Dependent Variable LNTSSECTOR	Entire Data Set	Aerospace	Automotive	Semiconductor
R^2	.58	.48	.61	.69
Adjusted R^2	.57	.46	.59	.68
Mean response	1.85	1.35	1.49	2.48
Observations	299	90	99	110
Intercept	-.994*** (.294)	-1.76 (.707)	-1.36 (.642)	-1.42*** (.392)
LNALLDOMRD Log domestic R&D Agreements	.513*** (.155) [13.4]	.786** (.327) [11.1]	.450 (.328) [7.69]	.250 (.202) [11.2]
LNAllTBORD Log trading-bloc only R&D Agreements	-.130 (.214) [-7.68]	.710** (.355) [14.4]	-.528* (.316) [-14.5]	-.221 (.384) [-35.3]
LNAllXTBRD Log cross-trading-bloc Agreements	1.01**** (.163) [26.3]	.072[a] (.326) [.849]	1.25*** (.330) [23.1]	.942**** (.221) [42.2]
LNAV3YrSales Log average 3-Year sales	.301**** (.047)	.003 (.002)	.305** (.098)	.510**** (.073)

NOTE: Standard errors are in parentheses. Significance indicated by the asterisks: (*) p<.1, (**) p<.05, (***) p<.001, (****) p<.0001. Transformed marginals are computed using the mean Y and X for the data included in each sector and are shown in the brackets [ ].
[a] p value is .83.

Table 5.11 indicates clearly the strong impact of domestic and international alliances on innovative output, and more especially international alliances.

It also underscores the differences among the sectors. As before, the explanatory power of the models, R^2, is somewhat less for the aerospace sector than for the less regulated and growing automotive and semiconductor markets.

In the highly innovative semiconductor sector, the impact of trading-bloc-only agreements is negative but non-significant, while truly international agreements are strongly positive and highly significant. Domestic agreements have a non-significant positive impact. In the automotive sector, in which the acquisition of patents is not as frequent, the experience of the semiconductor sector is replicated, only at somewhat reduced magnitudes. International agreements have a strong positive impact, domestic agreements a moderate, non-significant, positive impact, while trading-bloc-only agreements have a negative impact. *Only in the more regulated aerospace sector do international agreements have no impact on patent output, while trading-bloc-only and domestic agreements have significant positive impacts.*

Recall that the technical strength variable includes the number and quality of a firms patents. Thus, these results, which parallel but are stronger than those shown in Table 5.9, are indicative of true impact of the competitive structure on effective R&D cooperation. The positive coefficient on trading-bloc alliances in the aerospace sector may reflect cooperation motivated by survival concerns in that shrinking market. The negative coefficient for the same alliances in the automotive and semiconductor sectors may be due to intense European competition in those sectors. The positive and highly significant cross-trading-bloc coefficients in these same two sectors may be indicative of the positive effect of growing international markets on cooperative R&D.

Causation Test

One important issue is whether alliances cause increased patent production, or whether causation is the reverse. The easiest way to test causation is longitudinally. Sufficient data were acquired to conduct preliminary longitudinal analysis for this purpose.

Recall that the alliance data set consists of CATI agreements covering the years 1979 to 1989, and SDC agreements covering the years 1985 to 1992 with the strongest coverage beginning in 1989. The sector patent data are for the years 1988 to 1992.

To test causation, the impact of sector patent awards during 1988-1992 on (nearly) contemporaneous formations of SDC agreements can be tested. To do so the following additional variables are needed:

Dependent. SDCALLRD (all SDC research and development agreements) These are the total research and development agreements for the firms during the years 1985 through 1992, with the most thorough coverage beginning in 1989. In log form, this variable is named LSALLRD.

Independent. CATISECRD (CATI sector R&D agreements). These are the firms' research and development agreements in the CATI product group sector. The sum of this variable and SDCALLRD is the TOTRDAG variable used in the initial analysis above. In log form, this variable is named LNCSECRD.

In effect, these variables allow testing the impact of early R&D cooperative agreements and the level of current patent awards on the current formation of alliances. Two versions of the test are shown in Table 5.12, one without R&D spending as an independent variable and one with R&D spending included. The version with the R&D spending as an independent variable should be more accurate as R&D spending levels likely contribute substantially to a firm's willingness or ability to enter into cooperative research agreements. The significance of the R&D coefficient supports this contention.

Table 5.12 shows that while sector patents have a positive effect on the formation of contemporaneous alliances, the impact is small. And when R&D spending is added as a predictor, the influence of current sector patent awards is reduced further and is not significant.

Note the relative magnitudes of the coefficients. For the U.S. firms, $246 million in R&D spending has the same correlation with the formation of SDC R&D alliances as one prior R&D agreement. 586 patents over a 5-year period within the sector have a comparable correlation.[64] Clearly, prior experience with R&D agreements is much more influential than current levels of patenting, or current R&D spending. In the full data set, the influence of R&D spending is embedded (correlation coefficient=.806) in the patent variable (LNSECPATS) in the regression,

[64] Computed by dividing the marginals of the respective coefficients into the marginal for CATI sector R&D agreements, LNCSECRD.

so the coefficient on the sector patent variable is highly significant.[65] But the relative influence suggests the same relationship: in this full data set regression, 216 sector patents over five years have the same correlation as one prior R&D agreement from the CATI database.

Table 5.12

Causation Test of Patents on Alliance Formation

Dependent variable: LSALLRD	Full data set w/o R&D	U.S. firms w/ R&D
R^2	.61	.76
Adjusted R^2	.60	.75
Mean response	.644	.745
Observations	302	148
Intercept	.092 (.121)	.314 (.214)
LNAV3YRSALES Log average 3-year sales	-.018 (.020)	-.135 (.050)
LNAVRD8892 Log average R&D spending 1988-1992		.273**** (.058) [.005]
LNCSECRD Log CATI sector R&D agreements	.618**** (.056) [.649]	.694**** (.080) [1.23]
LNSECPATS Log sector patents	.153**** (.025) [.003]	.046[a] (.037) [.0021]

NOTE: The regression with R&D as a variable includes only U.S. firms.

[a]The non significant p score is .213.

Even though the patent coefficient is non-significant in the regression for U.S. firms alone, eliminating outliers in accordance with the procedure described above makes the coefficient highly significant. Therefore, it seems clear that current patents have a significant impact

[65] Moreover, missing variable bias may account for the some of the significance on this coefficient. See footnote 68, below, for a discussion of this bias and its computation. However, when outliers are eliminated, the coefficient is even more significant.

on current levels of alliance formation. However, the relative magnitude of the coefficients suggests that alliance experience has a much stronger impact on patent production than current patents have on alliance formation. To see this, compare the full regression in Table 5.12 with the Model 1 regression in Table 5.8. In the causality regression (Table 5.12), the marginal coefficient on LNSECPATS suggests a correlation of 333.3 patents with one additional R&D agreement. In contrast, in the Model 1 regression, every additional R&D alliance agreement adds 14.1 patents. Dividing 14.1, by 1 over 333.3, indicates that the influence of alliances on patents is some 4700 times more influential than that of patents on the formation of alliances.

The results seem plausible, as firms which are successful in obtaining patents are not likely to form alliances merely for the benefit of having more alliances. Rather, they are presumably motivated by a desire to build on past innovations and expand their technological knowledge. Hence, it seems more reasonable to expect causation to run from alliance formation to patent production, rather than the reverse. Despite the significance of the LNSECPATS coefficient for the full data set regression, the relative magnitudes of the correlation coefficients of this analysis support this conclusion.

It is true that the more active a firm becomes in forming alliances and obtaining patents, the more likely additional alliances will be formed. Part of this inertia can be traced by these regressions to the patents themselves. But the bulk of the influence is due to former alliances. Moreover, the influence of the alliances on patent production is many times stronger than that of patents on alliance formation.

Profitability Regressions and Scatter Charts

The profitability regressions of the aggregate patent data also show support for Hypotheses 1 and 1A. But the modeled relationships are not as strong. Several factors explain the weaker correlations. First, the relationship between research alliances and profits, as moderated by innovations, is not as direct as between alliances and innovations. The patents generated by R&D alliances may be temporally uncorrelated with

profitable sales of products based on the patents. Also, a variety of confounding firm, industry and governmental factors affect the year-to-year profitability of firms, introducing substantial error into the modeled relationships.

Second, because of non-normality in the profitability data and the regression residuals, regressions using the raw profitability data are problematical. Because no transformations are available for the profit data as they include many losses of large magnitude (negative values), outlier elimination is required to comply more closely with the least-square assumptions and improve model specification.[66] Analysis of the raw profit data is shown in Appendix A.

Sector disaggregation regressions are quite distinct, yet all are generally supportive of the main and subsidiary hypotheses.

Figure 5.3 shows the aggregate bivariate relationship between total research agreements and average profits. As can be seen, while the correlation is positive, the degree of variance explained by the TOTRDAG variable is very low: R^2 equal to .05.

Profits Regressions with Elimination of Outliers

Since, as shown in Appendix A, outlier elimination substantially improves the normality of the residuals, I elected to use the more accurate version of the regression models for the profitability analysis. Note that somewhat different observations are eliminated from each model in accord with the Weisberg prescription for outlier treatment.[67] (Weisberg, 1985). In Appendix B, the outliers eliminated and their respective studentized residuals are shown for each case.

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[66] See Appendix A for a description of those assumptions and how outlier elimination improves the regressions' consistency with the assumptions. The process of outlier elimination is described above.

[67] Consideration of the firms eliminated sheds light on why these observations are outliers. As explained in the text, the alliance-profit correlation is moderated by innovation outputs, and affected by numerous structural factors. The importance of structural circumstances is suggested strongly by the following list of outlying firms for Model 3, some of whose profits are much higher than would be predicted and some of whose profits are much lower: Boeing, Chrysler, General Electric, Ford, General Motors, Peugeot, Toyota, AT&T, Hewlett Packard, and IBM.

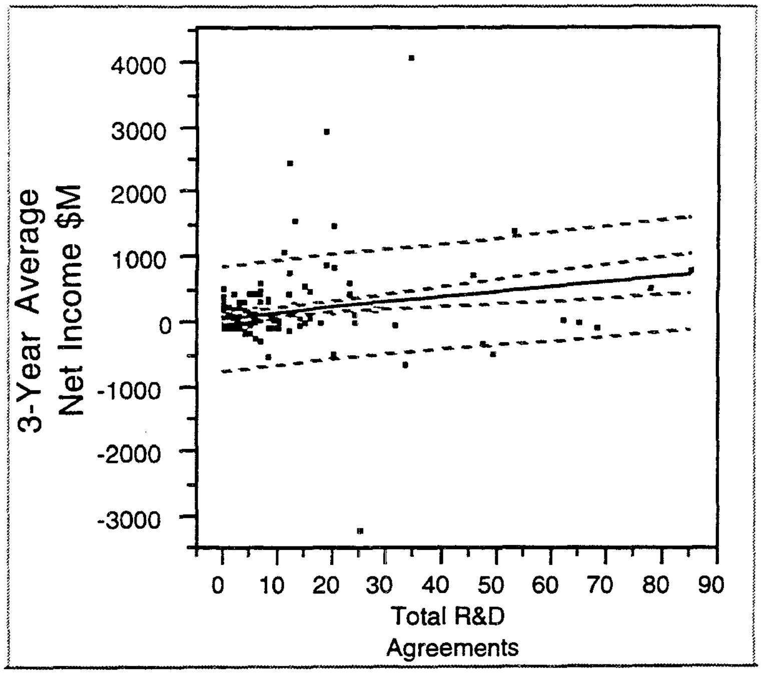

Figure 5.3—Average Profits as a function of Total R&D Agreements

NOTE: R^2 is .05, the number of observations is 327, the total F ratio is 16.5, the coefficient on total R&D agreements is 8.06 with a standard error of 1.98. It is significant at the .0001 level. The solid line is the least squares fit, the inner dotted lines are the confidence interval for the fitted line. The outer dotted lines are the confidence interval for the data.

The regressions in Table 5.13 show that *research and development agreements have a positive and significant impact on 3-year profits for Model 2.* For that model, the b_1 coefficient (TOTRDAG) is positive, supporting Hypothesis 1. Moreover, Models 3 and 4 show that *research agreements which cross trading-bloc boundaries have a strong positive impact.* In these models the b_{13} coefficients (ALLXTBRD) are greater than zero and greater than the b_{11} coefficients (ALLDOMRD), supporting Hypothesis 1A. However, in Model 1 the b_1 coefficient is non-significant and negative.

This negative coefficient for Model 1 is inconsistent with Hypothesis 1. But note that research and development expenses are moderately correlated with a firm's propensity to form cooperative

Table 5.13

Profitability Regressions After Elimination of Outliers

Dependent Variable: Average 3-Year Profits	Model (1)	Model (2)	Model (3)	Model(4)
R^2	.49	.88	.60	.88
Adjusted R^2	.49	.87	.60	.88
Mean response	68.8	24.3	61.2	19.2
Observations	293	142	292	141
Intercept	2.27 (9.59)	2.85 (10.1)	8.97 (8.04)	7.24 (9.71)
TOTRDAG Total R&D agreements	-.561 (1.01)[a]	12.3**** (1.01)		
AV3YRSALES Average 3-year sales	.016**** (.001)	.039**** (.003)	.015**** (.001)	.041**** (.003)
AVRD8892 Average R&D spending 1988-1992		-.848**** (.029)		-.844**** (.028)
AllDOMRD Domestic R&D agreements			-8.12*** (2.18)	6.65* (3.94)
AllTBORD Trading-bloc-only R&D agreements			-56.9**** (4.81)	
AllXTBRD All cross-trading-bloc agreements			11.4**** (2.35)	12.0** (4.05)

NOTE: Standard errors are in parentheses. Significance indicated by the asterisks: (*) $p<.1$, (**) $p<.05$, (***) $p<.001$, (****) $p<.0001$. Model 4 has no entry for ALLTBORD as the firms in the sample are only U.S. firms which have no such trading block agreements. A list of the firms eliminated from these regressions as outliers and their respective studentized residuals is in Appendix B.

[a]p value is .58.

research agreements TOTRDAG (correlation coefficient = .54). When the R&D spending variable is added as an independent variable (Model 2), the R^2 value nearly doubles, even though the number of observations is cut in half, and the negative sign on TOTRDAG becomes positive, and

significant. This suggests that missing variable bias may account for the negative sign on the total R&D agreements coefficient in Model 1. The bias cannot be computed exactly, however, as there are also many missing observations in moving from Model 1 to Model 2, and from Model 3 to Model 4. Missing variable bias may also account for the negative sign on domestic alliances in Model 3.[68]

It seems clear from Table 5.13 that *the overall impact of alliances on profits is positive (Model 2). Cross-trading-bloc alliances (Model 3 and 4) clearly have a significant positive impact. In contrast, trading-bloc-only agreements have a strong negative impact. Domestic alliances have a mild positive impact for U.S. firms in the data set, but for all firms the impact is negative.*

Comparing this table with Table A.2 in Appendix A, we see that eliminating outliers improved the R^2 in every case. Moreover, the impact of total R&D agreements is less negative in Model 1 and more positive in Model 2. For Model 3, the coefficients are comparable. The domestic agreements influence is somewhat less negative; the cross-trading-bloc agreements are about half as positive; but the impact of the trading-bloc-only agreements is just as strongly negative. In Model 4, the impact of domestic agreements has gone from negative and not significant to positive and significant at the 10 percent level. Cross-trading bloc agreements are still positive and significant, but at only about one-third of the magnitude.

Profits Regressions by Sector

The disaggregated analysis shown in Table 5.14 is computed using the raw data set for Model 3. One could argue that it may be more appropriate here to use the full data sets than the outlier corrected

[68] Missing variable bias is computed by multiplying the coefficient of the missing variable, in this case the AVRD8892 variable, by the regression coefficients of the missing variable regressed on all of the included variables. (Maddala, 1988). Performing that computation for Model 4 using outlier corrected data sets yields a bias value in the range of -8. To correct for bias, the bias values are subtracted from the coefficients in Model 3. Subtracting -8 (adding +8) to the Model 3 coefficients would make the coefficient on domestic alliances nearly zero.

versions. That is because the structural and individual factors, which make observations outliers in aggregated models, are particularly important in the sector disaggregations. Therefore, all observations may be necessary to capture the effect of these factors, and are included in Table 5.14.

Table 5.14

3-Year Profits Analyzed by Sector Using Model 3

Dependent Variable: 3-Year Profits ($M)	Aerospace	Automotive	Semiconductor
R^2	.74	.53	.51
Adjusted R^2	.73	.51	.50
Mean response	117	70.9	86.4
Observations	90	100	112
Intercept	-56.0*	1.70	4.76
	(30.53)	(37.9)	(25.9)
AllDCMRD Domestic R&D agreements	-.942 (18.8)	-152.7**** (18.1)	-7.30** (3.47)
AllTBORD Trading-Bloc-only agreements	-101.1**** (21.5)	1.66[a] (23.7)	-68.0**** (12.3)
AllXTBRD Cross-trading bloc agreements	37.1** (16.4)	-1.82[a] (32.5)	10.4** (4.76)
AV3YRSALES ($M). Average 3-year sales	.038**** (.006)	.037**** (.005)	.018**** (.002)

NOTE: Standard errors are in parentheses. Significance indicated by the asterisks: (*) p<.1, (**) p<.05, (***) p<.001, (****) p<.0001.

[a]The p values for both the trading bloc only and cross trading bloc coefficients for the Automotive sector are .94 and .96 respectively. Hence these variables have virtually no impact on the dependent variable profits.

Most striking about these regressions is the contrast between firms in the aerospace and semiconductors on one hand, and those in the automotive sector on the other. The regressions for aerospace and semiconductors follow the typical pattern for regressions in this

section of the research: negative influence of domestic and trading-bloc-only agreements, and positive influence for cross-trading-bloc agreements. In these two cases, the coefficients on the trading-bloc-only agreements are strongly negative and highly significant. Apparently, *European Union attempts to increase innovativeness and competitiveness, in the aerospace and automotive sectors, by encouraging E.U. alliances and restricting participation to European headquartered companies, have backfired.*[69]

This negative result in these two sectors is very significant given the substantial European investments in cooperative aerospace (i.e. Airbus) and semiconductor research. One explanation may be that European firms forced to cooperate across national boundaries by their governments may expend extra resources on the cooperative arrangements without developing the degree of trust needed to realize profitable innovations. Thus, the trading-bloc-only alliances may lead to higher costs without a commensurate return on investment than experienced by firms not involved in cooperative arrangements. Or, the necessary trust may develop but the return on the investment may not occur within the time scale measured with the research data. That could certainly be the case in the aerospace sector. But it doesn't explain the semiconductor sector whose rate of technological change has been very high.

In that sector, the negative trading-bloc-only coefficient may simply be due to lack of trust. Or it may be the result of a narrow technological search space. Technologies may be pursued which are at the leading edge regionally, but which cannot compete against more open global competitors. Indeed, firms which do not have any research alliances may be more open to all market developments, and more able to adapt to advances developed by international cooperators.

In sharp contrast is the automotive sector where domestic research agreements have a very strong negative and highly significant impact on

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[69] Indeed, the Europeans have given up on developing a fully independent technology base. Despite high tariffs, research subsidies and tough local-content rules, the Europeans apparently lost the memory chip and microprocessor markets to the Japanese and U.S., respectively, who have been more cooperative and who are building new factories and chip-design factories across Europe. (Levine, 1992).

profits, and the other two alliance classes have virtually no impact. With p values in excess of .94 on the coefficients for trading-bloc-only and cross-trading-bloc agreements, the only measurable influence is due to domestic agreements. While this does not directly support Hypothesis 1, it is supportive of the subsidiary hypothesis, for the relative impact of international agreements is more positive than that of domestic agreements. One immediately asks, "why is the automotive sector distinct?"

One reason is that General Motors and Ford have formed numerous domestic agreements[70] and suffered substantial losses[71] over the measurement period. Another might be that domestic competition is very intense in the automotive sector. Consequently, while domestic cooperation may lead to some innovations (see Table 5.9), it leads neither to much trust among partners nor to profits, but rather to substantial losses. In contrast, international cooperation leads to greater numbers of patents but has no impact on profits. This may be because innovations in the automotive sector may have very little impact on the financial results. Top of the line automotive products for which a temporary level of high profits can be charged may depend more on advertising for creating customers' perceptions of value than on the underlying technological advances. Also, according to one executive interviewed for this project, the reason may be due to the long-term investment profile of most international automotive alliances.[72] As indicated by the interviewed executive, in many cases it takes more than 10 years before automotive investments in international alliances begin returning profits.

As interesting as these regressions are, eliminating the outliers may provide a more accurate picture of the underlying relationships.

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[70] They have also formed substantial numbers of cross-trading-bloc alliances.

[71] As reported in the publicly available Moody's Company Data databases.

[72] See the full executive comments below in Appendix G.

Note that because the sample frame varies in each case, the observations eliminated are different than those for Model 3 in Table 5.13.[73]

Table 5.15

3-Year Profits Analyzed by Sector Using Model 3 with corrections for outliers

Dependent Variable 3 Year Profits ($M)	Aerospace	Automotive	Semiconductor
R^2	.79	.60	.76
Adjusted R^2	.78	.59	.75
Mean response	77.6	77.2	50.4
Observations	84	95	106
Intercept	-12.4 (12.5)	2.68 (14.5)	3.08 (11.0)
AllDOMRD Domestic R&D agreements	14.9* (7.88)	-40.9** (15.3)	-11.4**** (1.29)
AllTBORD Trading-bloc-only agreements	-55.2*** (14.0)	15.5* (9.37)	-62.4**** (5.20)
AllXTBRD Cross-trading bloc R&D agreements	32.9**** (7.96)	-17.3 (14.11)	17.7**** (2.92)
AV3YRSALES ($M) Average 3-year sales	.021**** (.003)	.022**** (.002)	.011**** (.001)

NOTE: The list of firms eliminated from these regressions and their respective studentized residuals is in Appendix B.

With the outliers removed from these Model 3 regressions, the overwhelming negative influence of trading-bloc-only agreements in the aerospace sector is moderated somewhat, but remains nearly as strongly negative as in the semiconductor sector. The negative impact of domestic alliances in the automotive sector is also moderated. This is coupled with trading-bloc-only alliances having a positive effect (significant at the 10 percent level), and cross-trading-bloc alliances

[73] The eliminated outliers for all profitability regressions for Section 5 are shown in Appendix B.

a negative influence. In contrast, cross-trading-bloc alliances remain strongly positive in the aerospace and semiconductor sectors. Moreover, domestic agreements in the aerospace sector shift from negative non-significance to positive and marginally significant. The impact of domestic agreements on semiconductor profits is even more negative.

Equally interesting are the sector disaggregated regressions for Model 4. These are U.S. firms alone. The trading-bloc-only variable has been eliminated and the research and development expense variable added. In addition, note that the because of multicollinearity problems for the disaggregated sample sets (between the R&D and sales independent variables),[74] the 3-year sales variable has been eliminated as an independent variable for these regressions. Table 5.16 shows the results with the outliers eliminated.

Comparing this corrected Model 4 from Table 5.16 with Model 3 from Table 5.15, all coefficients, except one, retain their sign and general magnitude. The sign on the aerospace domestic agreements goes from positive to negative and the impact of cross-trading-bloc alliances becomes very strongly positive. Thus, for U.S. aerospace firms, domestic cooperation has had a negative impact on profitability, while international cooperation has had a very strong positive impact.

Notice also that the impact of domestic alliances on profits is consistently negative across the sectors, and significant. For cross-trading-bloc alliances, the impact is positive for the aerospace and semiconductor sectors, but negative for automotive. Thus, U.S. aerospace and semiconductor sectors demonstrate similar alliance and

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[74] The correlation between R&D and sales in the semiconductor sector is .97, and .93 in aerospace. In automotive it is only .71. However, for consistency, I decided to show all three sectors without the sales variable. Regressions of the 3-year average net income (profits) variable were more sensitive to multicollinearity problems than the patent regressions, as the lack of a suitable transformation means that non-normality problems persist. (Eliminating all cases with losses in order to perform a log transformation would degrade the regressions as a substantial portion of the data would be eliminated). When these regressions included the sales independent variable, the signs and magnitudes of the coefficients of regression are unstable: They vary markedly when outliers are sequentially eliminated. Therefore, I elected to minimize the problem by eliminating the highly correlated independent variable, sales.

profit relationships. U.S. automotive firms, on the other hand, lose money as a result of alliance participation, domestic or international.

Table 5.16

3-Year Profits for U.S. Firms Analyzed by Sector Using a modified Model 4 with corrections for outliers

Dependent Variable: 3-Year Profits ($M)	Aerospace	Automotive	Semiconductor
R^2	.89	.53	.26
Adjusted R^2	.88	.47	.22
Mean response	104.6	9.37	20.33
Observations	50	28	58
Intercept	13.8 (13.9)	3.30 (6.14)	1.81 (15.7)
AllDOMRD Domestic R&D agreements	-15.6* (8.72)	-44.2** (13.8)	-10.4** (4.31)
AllXTBRD Cross-trading bloc R&D agreements	81.9**** (15.2)	-45.0** (14.1)	12.4** (5.17)
AVRD8892 Average R&D spending 1988-1992	.530*** (.154)	1.43**** (.288)	.293** (.129)

NOTE: A list of the firms eliminated from these regressions as outliers and their respective studentized residuals is in Appendix B. Model 4 was modified by deleting the 3-year average sales variable to compensate for the multicollinearity problem between the sales and R&D variables.

Possible explanations for these results may be that international alliances in the U.S. aerospace sector have been comparatively rare. Those that are formed may have contributed greatly to firms' profitability. One interviewed executive suggested a plausible reason for the strong international impact.[75] He indicated that teaming is the key to international aerospace sales, and such teaming often creates a monopoly in the international marketplace, leading to large profits. In contrast, domestic aerospace alliances have created no such monopoly.

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[75] For a full description of executive comments, see Appendix G.

And with shrinking defense spending, such alliances have been used to spread the available dollars to maintain the industrial base.

In semiconductors, the impact is parallel but somewhat less given that more international alliances have been, and are, being formed. In the automotive sector, the intensity of the domestic and international competition may cause the impact of alliances on the bottom line to be consistently negative, even though patent output increases.[76]

Causation Test

Causation for profitability has been determined in the same manner as for the patent regressions. However, the average net income (profits) variable is subject to significant multicollinearity problems when included as a regressor with average 3-Year sales and average R&D spending variables. This is because the correlation between the sales and R&D spending variables is a relatively high .81. Hence, I tested the inverse regressions on the full data set, but without including the R&D variable.

To test the influence of profitability on alliance formation, an additional variable is added, CATIRDPTX (number of CATI R&D agreement partners). This variable measures how many separate agreement partners have been created by the firm alliances. In this case, it measures the number of R&D partners involved in firm research agreements from the CATI database. The variable is a proxy of the firm's network embeddedness, its centrality in network of alliance relationships. (Granovetter, 1985) Prior network embeddedness has been found to be a good predictor of future alliance formation. (Shan et al., 1994). Table 5.17 shows the results with regressions both with and without the new predictor.

[76] See Table 5.10.

Table 5.17

Causation Test of Average Profits on Alliance Formation

Dependent Variable: SDCALLRD	(1)	(2)
R^2	.48	.60
Adjusted R^2	.47	.59
Mean response	2.84	2.84
Observations	300	300
Intercept	.55 (.366)	.40 (.322)
AV3YRSALES Average 3-year sales	.00002 (.00004)	.00006* (.00003)
CATISECRD CATI sector R&D agreements	1.03**** (.083)	.194* (.115)
CATIRDPTX CATI R&D agreement partners		.461**** (.049)
AVNI 3-year average net income ($M)	.001[a] (.0009)	.0005[b] (.0008)

[a]p value for the Average Net Income coefficient is .15

[b]p value for AVNI in Model (2) is .55. Neither is statistically significant.

This causality table has been run with all cases included. As many outliers are present in the data set, Table 5.18 repeats the analysis with the outliers eliminated.[77]

The outlier corrected test shows absolutely no influence of profits on the formation of agreements using test (1). When the prior influence of network embeddedness is included in the test, profits are *negatively* associated with the formation of agreements. Clearly, *causation runs from alliance formation to profitability, and not the reverse.* Indeed,

[77] The same test for outlier removal is used here as elsewhere in this research. All outliers with studentized residuals in excess of 2.0 are eliminated.

if anything, higher profits may be correlated with firms forming fewer, not more, research alliances

Table 5.18

Causation Test of Average Profits on Alliance Formation with Outlier Eliminated

Dependent Variable: SDCALLRD	(1)	(2)
R^2	.49	.75
Adjusted R^2	.49	.75
Mean response	2.40	2.48
Observations	295	292
Intercept	.51 (.314)	.40** (.159)
AV3YRSALES Average 3-year sales	-.00002 (.00004)	.00008**** (.00002)
CATISECRD CATI sector R&D agreements	1.13**** (.082)	.704**** (.069)
CATIRDPTX CATI R&D agreement partners		.120**** (.033)
AVNI 3-Year average net income ($M)	-.00005[a] (.0012)	-.0031**** (.0004)

[a]p value for the Average Net Income coefficient is .97 meaning, of course, AVNI has no effect on SDCALLRD.

Performance per R&D Employee for U.S. Firms

This data set provides sufficient information to test one additional performance variable for U.S. firms for which I have R&D data: five-year patents per 1000 R&D employees (the log transformed variable is abbreviated as LPTRDEMP). This variable is formed by dividing the total firm patents by the number of R&D employees in 1992, as can be inferred from the *Business Week* "R&D Scoreboard" and multiplying the result by 1000. Because this variable is normalized by the total number of R&D employees, I used total firm patent totals

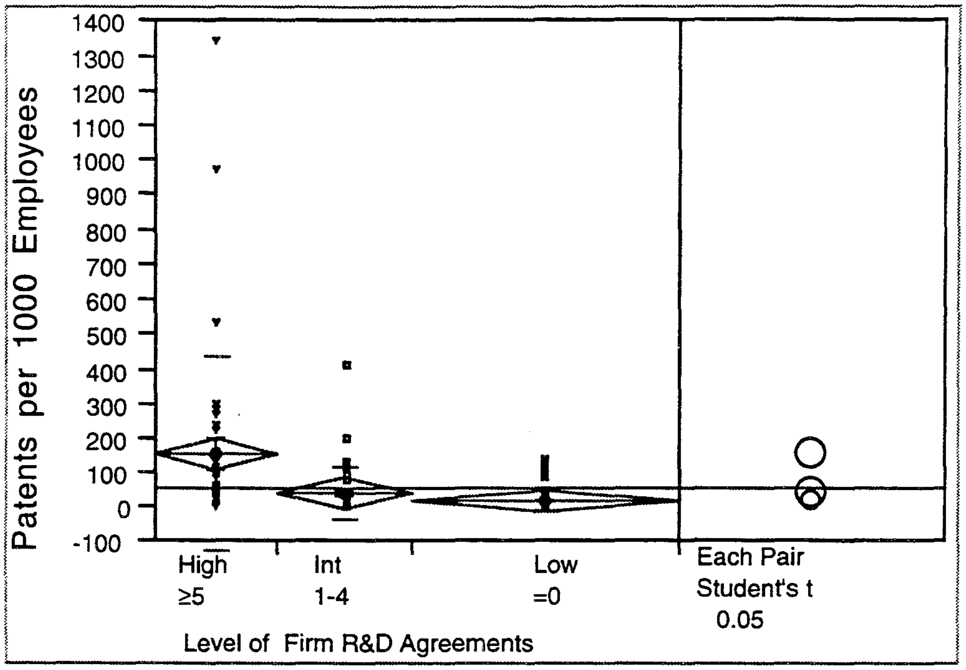

Figure 5.4—Five-year (1988-1992) total firm patents per 1000 R&D employees classified by the number of Total Firm Cooperative Research Agreements

NOTE: This one-way ANOVA table is interpreted as follows. The single horizontal line is the total response sample mean. The vertical height of the diamonds shows the 95% confidence interval for the mean. The line through the diamond is the group mean. The width shows the proportional sample size. The circles show the 95% confidence interval for comparing each pair. Overlapping circles are not significantly different; separated circles are. In this diagram high equals 5 or more agreements, intermediate equals 1-4 agreements and low equals zero agreements. The one-way ANOVA has an R^2 of .14 and an F ratio of 11.8 (prob. > F, 0.0000). The means are 156.5 for high, 37.7 for intermediate and 16.1 for low. The standard deviations are 281.1, 77.5, and 30.8, respectively.

rather than sector (product group) patent totals. Thus, these results cannot be compared directly with the regressions above.

The one-way analysis of variance (ANOVA),[78] Figure 5.4, shows that, on average, U.S. firms with 5 or more cooperative research agreements in

[78] This ANOVA analysis is meaningful in this context (and not in other analyses in this section) because the dependent variable here is normalized for size effects. Analysis of non-normalized dependent variables requires multiple regression to account for size effects.

the CATI and SDC database produced significantly more patents per one thousand R&D employees than firms with fewer than that number. The categories shown are high (5 or more agreements); intermediate (1 to 4 agreements); and low (zero agreements). As can be seen, the mean patents per thousand employees were significantly more for the high cooperating group than for the other two groups. The intermediate and low categories are not significantly different.

Table 5.19 summarizes the regressions of patents per 1000 R&D employees. Log transformations are used for all variables, and the regressions are enhanced by eliminating the outliers.[79]

As is clear from these regressions, *domestic R&D agreements have a uniformly negative impact on patent productivity, while international agreements have a positive impact for all but the Automotive sector.* Similarly R&D spending has a negative correlation with patent productivity for the aggregate and all sectors except Automotive. Thus, the automotive sector is somewhat distinct.

One possible explanation for the negative coefficients on the domestic R&D agreements variables is that the higher levels of competition in domestic markets, relative to those in international markets, reduce cooperation and absorb R&D resources. This explanation suggests that the negative coefficient for automotive cross-trading-bloc agreements is due to intense competition from international competitors.

The negative R&D coefficients in three of the regressions are curious.[80] They could mean that R&D spending reduces patent productivity because additional spending means additional new personnel who are less productive. Or, given that the R&D spending and patent time periods are coterminous, the coefficients could signal that

[79] See Appendix B for the outliers eliminated and their respective studentized residuals.

[80] At first blush this seems counter to well established findings that R&D investments contribute to total factor productivity. (Denison, 1985). However, the dependent variable, patent productivity, is quite distinct from total factor productivity. More importantly, these patent productivity regressions compare the effect of R&D spending on patent productivity with that of alliances. Executives can view these results as arguing for more international alliances and less in-house R&D (see the next footnote).

Table 5.19

Total Patents per 1000 R&D employees by Sector Using Model 4

Dependent Variable: LNPTRDEMP	Entire Data Set	Aerospace	Automotive	Semiconductor
R^2	.78	.86	.62	.82
Adjusted R^2	.77	.85	.56	.81
Mean response (mean raw value)	2.34 (54.8)	2.81 (92.8)	2.63 (42.7)	1.74 (27.8)
Observations	142	51	31	57
Intercept	-3.5**** (.337)	-4.39**** (.715)	-2.60* (1.36)	-3.90**** (.481)
LNAllDomRD Log domestic R&D agreements	-.346** (.131) [-4.65]	-.454* (.265) [-16.3]	-.433 (.529) [-6.57]	-.139 (.143) [-.646]
LNAllXTBRD Log cross-trading-bloc agreements	.293** (.135) [5.17]	.136 (.263) [4.89]	-.300 (.597) [-6.18]	.430** (.141) [2.95]
LNAVRD8892 Log average R&D spending 1988-1992	-.163* (.090) [-.043]	-.077 (.158) [-.052]	.208 (.256) [.029]	-.654**** (.139) [-.086]
LNAV3YRSALES Log average 3-year sales	1.02**** (.067) [.013]	1.11**** (.163) [.023]	.742** (.267) [.0056]	1.32**** (.138) [.012]

NOTE: Standard errors are in parentheses. Significance indicated by the asterisks: (*) p<.1, (**) p<.05, (***) p<.001, (****) p<.0001. Transformed marginals are computed using the mean Y and X for the data included in each sector and are found within the brackets [ ]. The regressions were corrected for outliers resulting in somewhat lower observations in each case. The dependent variable is the natural logarithm of the total patents per 1000 R&D employees.

successful firms are cutting back their R&D budgets and relying more on outside alliances to leverage their innovative capacity.[81] In light of the competition explanation for the automotive sector, the positive R&D coefficient in that sector may indicate that additional in-house

[81] Indeed, one vice president interviewed for this research indicated that deep cut-backs have been made and firms are relying on outside alliances, as well as on suppliers, to leverage their R&D capacity.

automotive R&D is more productive than alliances because of the lack of sufficient trust among domestic and international competitors.

The quality of these regressions is illustrated in Figure 5.5, which shows the leverage plot for the "whole model" of the entire data set regression. Leverage plots are related to added variable plots. For multiple regressions, they are comparable to scatter charts for simple bivariate regressions. They show, in one diagram, the model fit to the data, the residual errors, and what the residuals would be without the particular effect in the model.[82] The *whole model* shows the actual response values plotted against the predicted values, and shows in graphic form the same information found in the Analysis of Variance (ANOVA) report. (SAS Institute Staff, 1994).

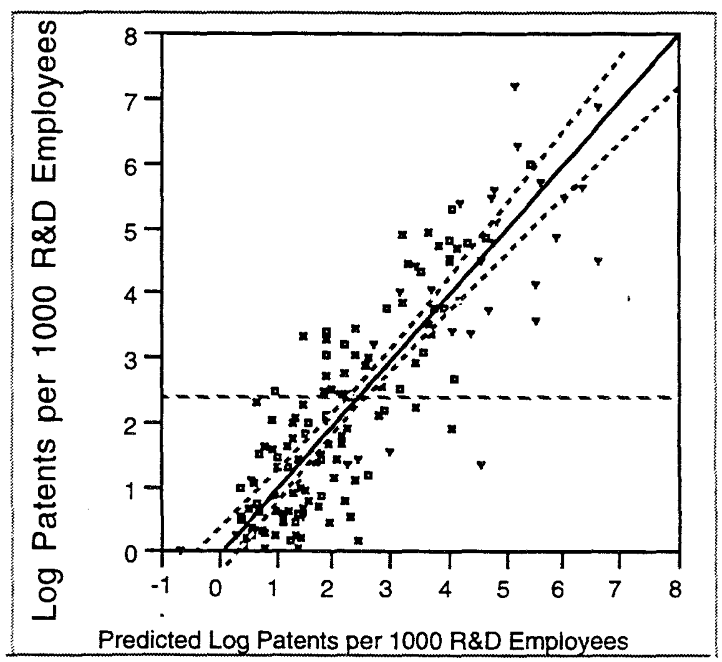

Figure 5.5—"Whole Model" Leverage Plot for Table 5.16 regression for the entire data set

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[82] The vertical distance from each observation point to the line of fit shows the residual. The vertical distance to the horizontal mean line shows what the residual error would be without the effect of all independent variables.

EXECUTIVE EXPLANATIONS OF, AND RESPONSES TO, THESE RESULTS

To begin to understand the results of the Hypothesis 1 analysis from the perspective of industry, I faxed a three page summary to 22 vice-presidents of the 75 firms which had responded to the initial research survey questionnaire.[83] I received responses back in the form of telephone interviews or faxes from 11 of the 22.

The distribution was evenly spread across the 3 sectors: 3 aerospace, 3 automotive (but 2 were from the same firm), and 5 semiconductor (but 2 of these were that no additional insights could be offered). Six of the eight firms for which I have responses are well-known large firms. Two are smaller, but both have active in-house R&D.

The questions I posed varied somewhat across the sectors, as I sought explanations for the findings discussed in this section. The executive comments and suggested explanations for the issues I raised are summarized in Appendix G.

It is quite clear from these that there are many dynamic sector-specific factors that influence the alliance-innovation and financial performance relationship. The one perception that stands out among these comments is that patent levels may be partially the result of alliance intentions, as patents may be used defensively, particularly when entering into international alliances. In other words, the high correlation this research shows between international alliances and patent production may be due to the defensive use of patents by firms anticipating entering into international research alliances. On the other hand, several executives suggested that increased markets and product expertise obtainable through alliance participation would generate more innovation and therefore patents.

TEST OF DEFENSIVE PATENT THEORY

The analysis databases have not yet been organized to test the extent to which patents are obtained for defensive purposes. To do so, the alliances would have to be organized on a year-by-year basis. Additionally, annual patent data would be required. However, the

[83] These were firms for which I already had fax phone numbers. In some cases I had communicated with them previously by fax transmissions.

following first-order analysis shows that the defensive patenting perception may be valid to some degree. Exactly to what degree is indeterminable from the data as now organized.

The idea of Table 5.20 regressions is that the influence of cross-trading-bloc agreements on patent awards can be compared with the influence of patent awards on the formation of cross-trading-bloc agreements. The table shows the outlier corrected regression of sector patents on CATI alliances and SDC alliances, with SDC alliances broken out by domestic, trading-bloc and cross-trading-bloc alliances. The table also shows the regression of cross-trading bloc alliances on CATI agreements and patents. The CATI alliances cover the early alliance years, 1979-1989. SDC alliances cover the later period, from 1985 to 1992. The sector patents were obtained during 1988 -1992.

The dependent variables are the log of sector patents and the log of SDC cross-trading-bloc agreements.

The independent variables for the first regression are the following:

LNCSECRD (log of CATI sector R&D agreements). These are the CATI agreements for the particular product group sector. The coefficient is strong, positive and highly significant. *Past alliances do influence patent production.*

LNSDOMRD (log of SDC domestic R&D agreements). These are the SDC domestic-only agreements for 1985-1992. The coefficient is moderately positive, and marginally significant at the 10 percent level. Thus, contemporaneous domestic alliances may motivate the acquisition of defensive patents. But the extent cannot be determined. The early SDC domestic agreements may be correlated with patents obtained in the latter part of the 5-year patent period (1988-1992).

LNSTBORD (log of SDC-trading-bloc-only R&D agreements). These are the E.U.-only SDC agreements for 1985-1992. The coefficient is negative and insignificant (p value = .96). Thus, contemporaneous E.U.-only agreements do not generate patents or motivate their acquisition for defensive purposes. As suggested during the executive interviews, one explanation for the lack of any impact may be the reliance on suppliers to develop new E.U. technology.

LNSXTBRD (log SDC cross-trading-bloc R&D agreements). These are the genuinely international research agreements for 1985-1992. The coefficient is very strong, positive and highly significant. The magnitude is twice that for the early CATI agreements and almost four times as strong as the coefficient on domestic SDC agreements. This coefficient could imply that defensive patenting is indeed happening. Or it could imply that early, 1985-1989 cross-trading-bloc agreements have a very strong impact on later, 1990-1992, patents. Or it could imply both. Since CATI agreements have a very strong impact on later patent output, direct impact from SDC alliance to patent output is likely. However, some portion may be due to defensive patent acquisition in anticipation of international alliance relationships.

The independent variables of the second regression include the log of 3-year sales, the log of CATI sector R&D agreements, and the log of sector patents. The impact of sales on the formation of SDC cross-trading-bloc agreements is negative but not significant. The coefficients on the CATI R&D agreements variable is positive and very significant. Past alliances do positively influence the formation of new agreements. Most important for this analysis is the positive and significant coefficient on the sector patents variable. Patent awards are correlated with the formation of cross-trading-bloc alliances.

The magnitude, however, appears quite small. As Table 5.20 shows, the relative impact of SDC cross-trading-bloc alliances on patent production is some 7,775 times greater than that of patent production on cross-trading-bloc alliance formation.[84] This result is ambiguous. On one hand, it could imply that firms forming international alliances also apply for, and eventually receive, higher numbers of patents, supporting the defensive patenting thesis. Or, it could imply very little evidence of defensive patents since patents only slightly influence the formation of SDC cross-trading bloc agreements. While this latter possibility suggests that the defensive patenting hypothesis may not fully account for the data, it does not, in of itself, refute the hypothesis. Firms

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[84] This is computed by dividing the marginal on LNSXTBRD as a predictor of patents, by the marginal of LNSecPats as a predictor of the formation of contemporaneous cross-trading-bloc agreements. (31.1/.004).

Table 5.20

Comparison of Impact of SDC (1985-1992) Alliances on Patent Production for 1988-1992 with impact of Patent Production on Cross-Trading-Bloc Alliance Formation

Dependent variable: LNSECPATS		Dependent variable LNSXTBRD Log SDC Cross-Trading-Bloc R&D Agreements	
R^2	.62		.60
Adjusted R^2	.61		.59
Mean response	2.18		.401
Observations	293		293
Intercept	-.208 (.243)	Intercept	-.050 (.096)
LNAV3YRSALES Log 3-year average sales	.252**** (.039)	LN AV3YRSALE	-.014 (.016)
LNCSECRD Log CATI sector R&D agreements	.549**** (.133) [15.2]	LNCSECRD	.412**** (.046) [.315]
LNSDOMRD Log SDC domestic R&D agreements	.231* (.127) [8.16]	LNSECPATS	.148**** (.021) [.004]
LNSTBORD Log SDC trading bloc only R&D agreements	-.015 (.294) [-1.10]		
LNSXTBRD Log SDC cross trading bloc R&D agreements	.856**** (.148) [31.1]		

may apply for patents in anticipation of alliance formation and then go ahead with alliance opportunities while the defensively obtained patents are pending. However, the data have not been organized to test the time-lagged correlations.

To the extent alliances motivate defensive firm-wide examinations of technology that requires patenting, two consequences may follow. One, firms active in alliance activity may be more aware, in an

organizational sense, of the state of the in-house technology and what needs to be learned from anticipated alliances to improve upon it. As such they will be better prepared to benefit from alliance participation. Two, the quality of the patent variable as a proxy for innovation may improve, as more in-house technical capability is captured by recorded patents.

I note also that the technical strength model regressions, Table 5.11, indicate a stronger correlation between cross-trading-bloc research agreements and the technical strength variable than shown in Table 5.8 for patents.[85] If defensive patenting accounted for the full impact of international alliances, one would not expect the technical strength regressions to show a stronger correlation than that of the number of patents.

Finally, one possible explanation for the patent productivity regressions in Table 5.19 is the degree of competition in the respective sectors. Defensive patenting may also explain the outcome. But the two explanations are inconsistent. If domestic competition explains the data, then defensive patenting would be more prevelant in domestic markets, not in international markets. If defensive patenting explains the positive results for international agreements, then what causes the negative coefficients on domestic agreements? As no rationale seems apparent, the more likely explanation for the results is the degree of competition. This, of course, weakens the defensive patenting reasoning.

While the available evidence is mixed, the weight of the evidence counters defensive patenting as a singular explanation. However, the possibility of some defensive patenting behavior clearly exists. And as several of the interviewed executives suggested it as factor, it is likely to some degree. I leave the definitive resolution of the magnitude of this effect to future research.

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[85] Moreover, a regression, not shown here, with the log of the sector technical strength substituted for the log of sector patents as the dependent variable in the Table 5.20 regression shows a higher R^2 (.68) and a stronger positive and highly significant coefficient for the cross-trading-bloc variable (1.02 versus the .856 shown in Table 5.20).

SUMMARY

Patent production, a proxy for innovation, has been shown to be positively influenced by the formation of alliances, and most strongly by the number of international cross-trading-bloc alliances. Such alliances give firms access to broader markets, increased customer feedback and additional technologies. All of these operate to increase the innovativeness of firms. While some patents may be obtained for defensive purposes before entering into alliances, particularly international alliances, the exact impact of this practice is indeterminate. What is clear is that the impact of alliances on patent production far exceeds the impact of patents on alliance formation.

For the entire data set (U.S. and international firms), profitability is improved by cross-trading-bloc alliance participation but depressed by domestic and trading-bloc-only alliances. For U.S. firms, profitability improves slightly with domestic alliances; while the impact of international alliances is greater. Moreover, causality has been shown to run from alliances to profitability, rather than the reverse.

For both patent and profitability models, sector factors play an important role. As suggested by comments of interviewed executives, these can be due to a variety of factors: the countries and purposes for the international research alliances, the nature and size of the country-specific markets and economies of scale factors, whether governments are the primary customers, and the degree of competitiveness in the domestic and international markets. Other factors may include the degree of industry globalization, how recently the alliances have been formed and how motivated alliance partners are to increase their innovative learning.

Clearly, these complex issues can best be understood at the sector level. And certainly for business planning and strategy purposes, such industry studies are required. For policy purposes, however, the finding that, in the aggregate, firms are more innovative and profitable as a result of alliance participation, and most particularly as a result of international alliance activity, is significant.

The next section explores the innovation-alliance connection in more detail including: (1) the impact of other communication variables and organizational learning strategies on innovation, (2) the relative impact of mutual learning, opportunistic (cautiously suspicious of the partner's behavior) and economically motivated attitudes on alliance performance, and (3) the impact of alliance experience on innovation and financial performance, and on the formation of new alliances.

6. DATA ANALYSIS AND RESULTS - PART II: SURVEY DATA HYPOTHESES 2, 3, 4 AND 5

SECTION OVERVIEW

While Section 5 describes the R&D alliance impact on patent output and profitability, this section explores the added influence of executive attitudes toward alliances, communication quality and organizational learning strategies. In addition, this section explores the impact of these variables on the perceptions of success, frequency of transaction cost problems, and the formation of new R&D alliances. While the breadth of the tests is increased, the data for testing the three hypotheses of this section are limited to the 74 firms which responded to the research survey. And because some of the returned questionnaires were not complete, the effective number of cases is reduced to 62, 64 or 69, depending on the variables used in the tests.

The results of the three tests are presented first in Tables 6.1 and Table 6.2. The analysis indicates that external cooperative agreements, external communication and organizational learning practices are all, but not equally, important. In addition, executive attitudes are significant; and prior alliance experience does make a difference for some outcome variables. A detailed explanation of the data, variable operationalization, statistical techniques and conclusions follows.

After discussing the results of the Section 6 analysis, I describe the data used for the analysis and the statistical methodology. Then, the actual analysis is present in two parts. The analysis of the Hypothesis 2 models is presented first, followed by the analysis of the Hypothesis 3, 4 and 5 models. In each case, I discuss the dependent and independent variables, the models, the corrective transformations and procedures, the descriptive statistics and actual regressions. The regressions for Hypothesis 2 are shown in Table 6.5 and those for Hypothesis 3, 4 and 5 in Table 6.9.

THE RESULTS OF THE HYPOTHESIS TESTS

Hypothesis 2: The impact of learning connections and communication flows

This hypothesis tests the benefits of organizational learning factors on innovation and profitability. The factors include external information acquisition and internal information processing. The hypothesis is restated here:

> 2. Firms operated to acquire extensive technological information more rapidly (multiple external alliances, better external communication flows and favorable executive attitudes toward alliance learning opportunities) and designed to process technological information better (integrated R&D, cross functional teams, better internal communication flows, and organizational learning practices) will be more innovative and profitable.

Table 6.1 indicates that firms which develop extensive external and internal organizational connections are more innovative and profitable. Consistent with the results from Section 5, the impact of multiple R&D agreements on patent production is strong. Multiple R&D agreements serve as rich sources of technical and market responsive information that leads to more innovations protected by patents. Executive attitudes focused on the learning opportunities of alliances have a significant positive impact. The influence of external communication quality is also positive and significant. Organizational learning structures within the firm have a positive significant impact, while a top-down or hierarchical design has a negative and significant influence. Finally, R&D spending has a non-significant positive influence.

Profits are influenced positively by the number of R&D agreements. None of the other communication, organizational structure or attitudinal variables have significant impacts. The most important non-significant effect is the negative mutual learning focus coefficient.

Table 6.1

Summary of Significant Hypothesis 2 Regression Coefficients

	Patents	Profits
Mutual learning focus	+	..-
Total R&D agreements	++++	++
Average annual 3-year sales	..-	++++
External info quality	+	..+
Organizational learning index	++	..-
Top down index	--	..+

NOTE: Key: (..+/-) Non-significant positive or negative coefficient. (+) Positive correlation significant at 10 percent level. (++) Positive correlation significant at 5 percent level. (+++) Positive correlation significant at 1 percent level. (-,--, ---) Negative correlations significant at respective 10, 5 and 1 percent levels.

This pattern indicates that Hypothesis 2 is strongly supported by the data for the Patents model. The Profits model provides some support with the positive significant coefficient on the Total R&D Agreements variable. This confirms the Hypothesis 1 findings. But as will be discussed below, the organizational learning variables for the Profits model are all non-significant and, except for the External Information Quality variable, the signs of their coefficients are reverse from those posed by the hypothesis.

Hypothesis 3, 4 and 5: The Impact of Executive Attitudes, Communication Quality and Experience on Alliance and Innovative Performance

These hypotheses test whether (1) pre-existing executive attitudes, beliefs and perceptions about the opportunities and threats of alliances, (2) external communication quality, and (3) alliance experience, make a difference in alliance performance and the rate of forming new alliances

> 3. Firms whose executives focus more on the learning opportunities presented by alliances will form more alliances and perceive greater success with their ongoing alliances.

3A. Firms whose executives focus more on the threats of partner opportunism will form fewer alliances and perceive more transaction cost problems with ongoing alliances.

4. Firms whose executives perceive better communication quality from alliance partners will form more alliances, and perceive greater success with their ongoing alliances and fewer transaction cost problems.

5. Firms with more R&D alliance experience will form more new alliances, and perceive greater success with their ongoing alliances and fewer transaction cost problems.

Table 6.2 shows the significant coefficients for the three regression models used to test these hypotheses. None of these hypotheses are disproved by the data. Rather, the data show support for Hypothesis 3, stronger support for 3A, and support for Hypotheses 4 and 5.

Table 6.2

Summary of the Significant Coefficients for the Hypothesis 3, 4 and 5 Regressions

	Success Index	Problem Frequency Index	New R&D Agreements
Mutual learning focus	+	~	++
Opportunism focus	..-	+++	--
External info quality	++++	..- p=.12	..-
Total R&D agreements	..+ p=.11	..-	NA
Prior CATI R&D agreements	NA	NA	++++

NOTE: Key: (~) No significance (p>.8). (..+/-) Non-significant positive or negative correlation. (+) Positive correlation significant at 10 percent level. (++) Positive correlation significant at 5 percent level. (+++) Positive correlation significant at 1 percent level. (-,--, ---) Negative correlations significant at respective 10, 5 and 1 percent levels.

As discussed below, the primary findings are the following:

- Firms whose executives focus more on mutual learning opportunities of alliances form more alliances and perceive greater success with ongoing alliances.
- An executive focus on potential opportunism is correlated with lower alliance formation rates and higher perceptions of transaction cost problems with ongoing alliances.
- Better external communication quality is correlated with fewer transaction cost problems and highly correlated with greater perceptions of success.
- Increased alliance experience has a positive effect on perceptions of success. Moreover, past alliance experience has a very strong impact on the formation of new alliances.

It is evident that the overall Section 6 analysis generally provides support for the last four hypotheses. In general, cooperative research alliances activity and experience, and organizational learning strategies, have positive impacts on innovation outcomes and alliance success. Also, as in Section 5, R&D alliances positively affect financial performance outcomes. But the impact of organizational learning factors on profitability is inconclusive and not as predicted.

Thus, analysis of the data suggests that alliance strategies do not completely replace economic, opportunism and appropriability concerns. Rather, the organizational learning perspective and cooperative alliance strategies seem to be emerging as a useful extension on competitive business practice.

ANALYSIS DETAILS

The Data

The data for testing the hypotheses in the section consist of the questionnaire responses combined with the pre-existing CATI, SDC and CHI Research alliance and patent databases. These data comprise Analysis Database 4.

As shown in Table 4.7, the questionnaires are fairly evenly split between domestic U.S. firms (41) and international firms (33). However, they are more heavily represented by firms in the aerospace sector (39) than automotive (19) or semiconductor firms (16).

Not all of the respondents provided the requested financial information. In those cases, where data from Moody's were available, they were added to the database record for the firm. For six (6) questionnaires no financial data were available from any source. Therefore, the questionnaire data for such firms can be used only where financial information is not required in the analysis.

Statistical Methodology

The statistical methodology is basically the same as used in Section 5. Where variables are highly skewed, log transformations are used to normalize the data and improve consistency with the linear regression assumptions. In this section, I eliminate outliers from every regression by setting aside all cases with studentized residual values in excess of 2.0. However, as the participants in the survey and their responses to the questionnaire are confidential, no documentation of the residuals will be provided.

ANALYSIS OF HYPOTHESIS 2: THE IMPACT OF LEARNING CONNECTIONS AND COMMUNICATION FLOWS ON INNOVATION AND PROFITABILITY

Hypothesis 2 tests the overall impact of organizational learning determinants on patent production and profitability. These include external information connections (executive attitudes toward alliances, number of alliances, external communication quality with R&D partners) and internal organizational design, communication flows and R&D spending.

Two dependent and eleven independent variables are used to test Hypothesis 2. Nine of the variables are from questionnaire data, and two (Sector Patents and Total R&D Agreements) from the pre-existing patent and alliance data.

Dependent Variables

Log Sector Patents. This is the total number of patents obtained by the responding firms in their respective sectors. This is the same output variable tested in Section 5. Because the distribution of the patent data is highly skewed (see Table 6.3, below) these data are transformed to logarithm values.

Profits. This is the 3-year profits value as reported on the questionnaires. Where profit data were not supplied by the respondent, they were added from the Moody's Corporate Data if available. The unit of measurement is millions of dollars. Because the values are both positive and negative, no transformation of the data is made.

Independent Variables

The numerous independent variables needed to test the influence of organizational learning factors can be divided into several groups. The first division separates the variables into external and internal factors.

Within the external division are the following subdivisions and variables: attitude toward alliances (mutual learning focus index, opportunism focus index and economics factors focus index), external connections (total R&D agreements, and average 3-year sales), and external communication quality index.

The internal factors include the organizational learning index, top down index, internal communication quality index, QFD (degree of R&D integration), and 3-year average R&D budget.

As is evident, most of these variables are indexes. These were created by adding the responses to the relevant questionnaire questions and then normalizing by the total possible score. The use of such finite scaled indexes in this manner is fairly standard. (Cohen, 1977; Torgerson, 1958). The internal reliability of such aggregate scales, relative to the constituent responses, is estimated by Cronbach's alpha. (Cronbach, 1951)

External Factors

Attitude Variables

Question 13 on the questionnaire sought information about executive attitudes toward alliances. This question posed a hypothetical situation. "Suppose you have been presented plans to enter into an R&D alliance. Please indicate the importance of each factor in deciding whether to recommend entering into the alliance:.." Then the questionnaire asks for responses to each of 17 factors or considerations. These can be divided into three groups: economic factors, learning factors and opportunism factors. Thus, the question contemplates that the alliance decision is made on the basis of considerations which are economic, or colored by the learning opportunities and opportunism threats that alliances present. The normalized responses to the three categories of questions yields the three primary independent variables for this hypothesis test.

Mutual Learning Focus index. This is the normalized responses to questions 13 e, f, g, j, n, and q. These include the potential to commercialize new technologies faster, to learn new technologies and processes, form increased connections with target markets and consumers, enhance long-term learning and increase innovation, manufacturing and marketing expertise. It also includes the perceived opportunity to share in the creation and benefits of new technologies and markets, and the potential for developing high levels of trust. Cronbach's alpha for this index is a rather low 0.51.[86] Hence, the index does not measure accurately what the component questions are asking. The problem may be that the variances of the constituent questions are low, suggesting that improved question design may be needed. The standard deviation is the lowest of all indexes, .102, for the spread of 0 to 1. Nevertheless, the index was used as computed, in comparison with the opportunism focus and economic focus variables. These variables have much better alpha values.

Opportunism Focus Index. This is the normalized value of responses to questions 13 h, i, l, m, o, and p. It includes such factors as the

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[86] Nunnally suggests that alpha values in the range of .5, while low, are suitable for research purposes. (Nunnally, 1978)

ability to appropriate maximum short to medium term benefits from alliance research, the cost of monitoring partner performance, the ability to gain more information than is shared, the costs to the firm if the partner fails to perform, the risk of losing the fruits of alliance research, the risk of opportunistic behavior of the partner, and the potential for detecting, monitoring and preventing it. Cronbach's alpha for this index is 0.76.

Economic Focus Index. This is the normalized value of responses to questions 13 a, b, c, d and k. It includes factors typically found in the economic literature as primary reasons for entering alliances: risk sharing and overall cost reduction, accelerating the return on investment, sharing investments in labor and equipment and the up front cost of establishing the alliance. Cronbach's alpha is a sufficient 0.73.

External Connections

Total RD Agreements (TotRDAG). The total number of cooperative R&D agreements formed between 1979 and 1992 as reported in the CATI and SDC database. Because the distribution is skewed, the log value is used for the patent regressions (for which the outcome variable is also a log transformed variable). Raw values are used for the profits and learn index regressions.

3-Year Average Annual Sales. This is the reported 3-year sales figure for the responding firms. The variable primarily controls for size effects. Where sales numbers are not reported on the questionnaires, data from Moody's are substituted if available. The variable is transformed to log values for the patent regressions.

External Information Quality

External Information Flow Quality (Inflow-Ext.) This is the normalized index of responses to questions 14 a and b.

> What is the overall quality of information communicated to you from the following in terms of frequency, timeliness, usefulness and value for the innovation activities of the firm? a. R&D Managers at alliance firms, b. R&D managers at consortia firms.

The total score of responses is added and divided by 14, yielding a range of 0 to 1. As the quality of communication will vary from alliance to alliance and consortia to consortia, the question asks for the average level of communication quality among all firm alliances and consortia.[87]

Internal Organizational Learning Factors

These factors include organizational design, communication quality, degree of R&D integration, and R&D spending.

Organizational Design

Learn Index (LearnIndex). This index measures the degree to which the firm has implemented organizational learning strategies. The index is computed by summing the responses to questions 12 e through h and dividing by the total possible score. The questions ask about the importance of the following firm strategies, as indicated by the firm's planning, organizational design and implementation efforts:

- Individual business awareness by base level employees and responsibility for solving problems arising from changing market conditions, customer needs and technological demands.
- Problem solving, quality improvement and process re-engineering with cross-functional teams.
- Individual learning at all levels.
- Increasing overall organizational learning capabilities at all levels with enhanced communication technologies (e-mail, groupware, etc.) and a highly interactive and cooperative culture.

Top-Down Index. This index measures the degree to which the firm is organized and operated as a traditional hierarchy, with information flowing up and down the structure, to and from the top of the hierarchy where the learning is centered and decision-making occurs. The index is

[87] The consortia numbers from the questionnaire responses are not included as regressors as the values are scaled, rather than direct counts of consortia participation.

computed by summing the responses to questions 12 a through d and dividing by the total possible score. The questions ask about the importance of the following firm strategies, as indicated by the firm's planning, organizational design and implementation efforts:

- Top-down strategic planning by management
- Communication of top-level strategy and vision to all employees
- Faithful adherence by firm managers to top management's strategy, visions and plans.
- Implementing management strategies and vision at all levels.

Internal Information Flow Quality (Inflow-Int.). This is the normalized index of responses to questions 14 c and d.

> What is the overall quality of information communicated to you from the following in terms of frequency, timeliness, usefulness and value for the innovation activities of the firm? c. Vice-President of Marketing for the firm, and d. Vice-President of Manufacturing for the firm.

Normalization is the same as for the Inflow-Ext. variable. This question replaced several questions about cooperativeness, trust and communication frequency among executives. The idea of the question is that communication quality from other executives within the firm would reflect the overall internal communication environment of the firm.

Degree of Internal R&D Integration (QFD). This the normalized response to question 15. This question measures the degree of internal integration of R&D processes. QFD, or quality functional deployment, is an approach for encouraging communication and cooperation among all functions involved in the innovation and development process. (Cox, 1992; Eureka, 1988; Griffin & Hauser, 1992). The question contrasts such integration with the traditional method of sequential phase reviews for managing the research process.[88]

3-year Average Annual R&D Spending (3YRAVGRD). This is the reported 3-year average annual R&D budget figure for the responding

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[88] This method reflects, of course, the linear model of innovation.

firms. The variable is most closely correlated with the 3-year sales variable (see Table 6.7, below). But it is also correlated with the Total R&D agreements variable, and therefore adjusts the impact of alliances by controlling for research spending effects. The variable is transformed to log values for the patent regressions.

Hypothesis 2 Models

The linear models relate the impact of the external and internal organizational learning factors on patent production and profitability.

(1)

$$
\begin{aligned}
\ln(\mathrm{SecPATS}) = {} & a_o + b_1\mathrm{MutualLearnFocus} + b_2\mathrm{OpportunismFocus} \\
& + b_3\mathrm{EconomicsFocus} + b_4\ln(\mathrm{TotalRDAgreements}) \\
& + b_5\ln(\mathrm{Avg3yearSales}) + b_6\mathrm{ExternalInfoFlowQuality} \\
& + b_7\mathrm{OrganizationLearnIndex} + b_8\mathrm{TopDownIndex} \\
& + b_9\mathrm{InternalInfoFlowQuality} + b_{10}\mathrm{QFD} \\
& + b_{11}\ln(\mathrm{3yearAvgR\&DBudget}) + e_r
\end{aligned}
$$

(2)

$$
\begin{aligned}
\mathrm{Profits} = {} & a_o + b_1\mathrm{MutualLearnFocus} + b_2\mathrm{OpportunismFocus} \\
& + b_3\mathrm{EconomicsFocus} + b_4\mathrm{TotalRDAgreements} + b_5\mathrm{Avg3yearSales} \\
& + b_6\mathrm{ExternalInfoFlowQuality} + b_7\mathrm{OrganizationLearnIndex} \\
& + b_8\mathrm{TopDownIndex} + b_9\mathrm{InternalInfoFlowQuality} + b_{10}\mathrm{QFD} \\
& + b_{11}\mathrm{3yearAvgR\&DBudget} + e_r
\end{aligned}
$$

To disprove Hypothesis 2, the signs on all b coefficients, except b_2 and b_8, and the control variables b_3, b_5 and b_{11}, would be negative and significant. Positive signs on b_1, b_4, and b_6, b_7, b_9 and b_{10}, and a negative sign on b_2 and b_8, support the hypothesis.

Transformations and Outlier Corrections

The patent model is based on the following form:

$$\ln(Y_i) = a_o + b_1 \ln(X_i) + b_2 X_j + u_i$$

This is equivalent to the following untransformed model:

$$Y_i = e^{a_0} X_i^{b_1} e^{b_2 X_j} e^{u_i}$$

Note that the marginals for the b_1 coefficients (log transformed independent variables) are computed as described above in Section 5. For the b_2 coefficients, the marginals are computed as follows:

$$b_i \overline{Y}$$

Also note, that for all regressions in Section 6, outliers are eliminated in accordance with the procedure described above at page 69 to improve the specificity of the models. In each case, the particular observations eliminated varies. To preserve the confidentiality of the survey respondents and their responses, no details will be provided on the eliminated cases. However, the number of cases eliminated for each regression is cited in footnotes.

Hypothesis 2 Descriptive Statistics and Correlations

Tables 6.3 and 6.4 show the summary statistics and correlations for the variables used to test Hypothesis 2. Note that the alpha column reports the Cronbach's alpha value. (Cronbach, 1951). This was computed for the indexes which are composites of answers to more than one questionnaire question.[89]

[89] Alpha measures the internal-consistency reliability of the index. In other words, it measures whether the variance of the composite index is equivalent to the variance of the constituent sub-responses. The equation used to calculate alpha is the following:

$$\alpha = \frac{n}{n-1}\left(1 - \frac{\sum \text{Variance}_{\text{subtests}}}{\text{Variance}_{\text{test}}}\right)$$

A value of .8 is considered very good for internal consistency reliability. A value of .5 is generally considered quite low.

Table 6.3

Descriptive Statistics

Variable	Mean	Median	75%quartile	Maximum Value	SD	alpha
Sector patents	114.3	7.0	74.2	2144	319.9	NA
Profits	234.8	19.0	266.5	4059.0	593.0	NA
Mutual learning focus	.727	.71	.80	1.0	.102	.51
Opportunism focus	.534	.52	.635	.90	.151	.76
Economics focus	.696	.70	.80	1.0	.142	.73
Total R&D agreements	7.3	2.0	8.0	68.0	13.5	NA
Average 3-year sales	7474	790	8325	95356	15621	NA
External info quality	.57	.64	.71	1.0	.24	.74
Org. learn index	.764	.77	.82	1.0	.127	.74
Top down index	.78	.81	.89	1.0	.161	.84
Internal info quality	.66	.71	.86	1.0	.21	.73
QFD- integrated R&D	.55	.57	.75	1.0	.29	NA
3-yr avg R&D spending	468.0	50.0	371.7	8098.5	1159.1	NA

NOTE: Dependent variables are above the line, independent variables below it. See footnote 89 for a description of the alpha computation.

As can be seen, the 74 firms in the survey sample are more likely to be involved in cooperative agreements than the average of those in the full research sample frame. The median Total R&D Agreements value is 2.0 and the average, 7.3, is 50 percent more than that for the Hypothesis 1 data set, 4.56 (see Table 5.1). The same is true of the average profits.

Two potential problems involve aggregate Organizational Learn Index and Mutual Learning Focus Index. The standard deviation of the Learn Index seems low. However, the alpha value is a respectable .74. Thus, confidence in the internal reliability of the Learn Index is sufficient. However, the standard deviation on the Mutual Learning Focus is only .102, and its alpha value a low .51. Because the variances on the responses aggregated to form the Mutual Learning Focus Index are low, the significance of the index's regression coefficients should be discounted somewhat.[90] This problem points to necessary improvements in the questions themselves.

Table 6.4 shows the correlations of all independent variables used to test Hypothesis 1.

[90] But see footnote 86 for support for using this index.

Table 6.4

Hypothesis 2 Independent Variable Correlations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) Mutual learn focus	1.0	.45	.47	.17	.10	-.03	.11	.31	.24	.09	.08
(2)Opportunism focus	.45	1.0	.51	-.12	-.27	-.13	-.09	.07	.14	-.01	-.15
(3)Economics focus	.47	.51	1.0	.04	-.09	.16	.10	.29	.26	.22	.03
(4)Total R&D agreements	.17	-.12	.04	1.0	.43	.16	-.02	.14	-.02	.25	.16
(5)3-year Avg sales	.10	-.27	-.09	.43	1.0	.15	.16	.19	-.10	.12	.41
(6)External info quality	-.03	-.13	.16	.16	.15	1.0	.36	.15	.16	.24	.23
(7)Organization learn index	.11	-.09	.10	-.02	.16	.36	1.0	.45	.08	.28	-.05
(8)Top down index	.31	.07	.29	.14	.19	.15	.45	1.0	.22	.35	.03
(9)Internal info quality	.24	.14	.26	-.02	-.10	.16	.08	.22	1.0	.26	.18
(10)QFD	.09	-.01	.22	.25	.12	.24	.28	.35	.26	1.0	.09
(11)3-year avg. R&D spending	.08	-.15	.03	.16	.41	.23	-.05	.03	.18	.09	1.0

Examination of the correlation chart indicates no potential multicollinearity problems among the independent variables.

Hypothesis 2 Regressions

Table 6.5 shows the actual regression coefficients for the models illustrated above. As explained above, all of these regressions have been corrected for outliers by eliminating cases whose studentized residuals exceed the 2.0 cut-off magnitude.[91]

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[91] Three outliers were eliminated from the patent regression and four from the profits regression.

Table 6.5

Hypothesis 2 Regressions

Dependent Variable	Log Sector Patents	Profits
R^2	.75	.76
Adjusted R^2	.70	.70
Mean response	2.49 raw:114.3	191.9
Observations	61	58
Intercept	-4.47** (1.73)	75.5 (203.2)
External Organizational Learning Factors		
• Attitude Variables		
Mutual learning focus b_1	3.82*$^{p=.055}$ (1.95) [440.4]	-292.5$^{p=.3}$ (275.7)
Opportunism focus b_2	0.600 (1.44)	101.7 (198.6)
Economics factors focus b_3	-.241 (1.46)	17.5 (200.8)
• External Connections		
TOTRDAG Total R&D agreements Log for patent regression b_4	1.26**** (.190) [17.5]	8.07** (2.35)
AV3YRSALES Log for patent regression b_5	-.0163 (.143)	.0178**** (.004)
• External Communication Quality		
Information flow quality-external b_6	1.51*$^{p=.068}$ (.811) [174.1]	104.9 (116.0)
Internal Organizational Learning Factors		
Organizational learning index b_7	3.14** (1.54) [362.0]	-99.4$^{p=.67}$ (231.5)
Top down index b_8	-2.93** (1.27) [-337.8]	166.7 (171.9)
Information flow quality-internal b_9	1.17$^{p=.16}$ (.822) [134.9]	-46.3 (118.2)
QFD integration of R&D b_{10}	-.0551 (.096)	1.13 (13.4)
3-year average R&D spending Log for patent regression b_{11}	.127$^{p=.38}$ (.146) [.031]	.080$^{p=.12}$ (.050)

NOTE: Standard errors are in parentheses. Significance indicated by the asterisks: (*) p<.1, (**) p<.05, (***) p<.001, (****) p<.0001. Marginals are indicated within the brackets [ ].

Clearly Hypothesis 2 is not disproved by either of these regressions. As explained above, to disprove Hypothesis 2, the signs on all coefficients, except b_2 and b_8, and the control variables b_3, b_5 and b_{11}, would be negative and significant.

Patents

For the patent model, the regression coefficients in all organizational learning categories show support for the hypothesis. The significant coefficients supporting the hypothesis include the strong positive coefficient for the mutual learning focus (p=.055), the very strong positive coefficient for total R&D agreements significant at the .01% level, the positive external information flow quality (p=.068) and the organizational learning index, positive at the 5% level. Because organizational learning designs are often posed as remedial alternatives to top-down hierarchies, the negative Top Down Index coefficient, significant at the 5% level, also supports the hypothesis.

These results support the findings in Section 5 and provide context for the alliance effect on patent output. The more that firms are connected with other firms, the more executives recognize the learning benefits of alliances and establish good communication flows with alliance partners, the more innovative the firms will be. This will be enhanced by an internal organizational design that favors organizational learning strategies over top-down hierarchies. Note that R&D spending contributes in a positive, but not significant, manner. Hence, this analysis implies that R&D alliances are more important than additional R&D investments.

Only the non-significant opportunism focus and QFD (internal R&D integration) coefficients fail to support the hypothesis. The economics factors focus and 3-year average annual sales are control variables. Hence, the negative signs on the non-significant coefficients for these variables are irrelevant for this test.

On balance, the patent model regression shows strong support for Hypothesis 2. External attitudes favoring alliances, multiple external connections and good communication flows all significantly enhance patent performance. The same is true of internal organizational

learning strategies. Internal communication flows and R&D integration either do not have the predicted impact, or (the more likely case) the questions and responses were inadequate to sufficiently test the effect of these variables

Profits

The profits model neither refutes nor supports Hypothesis 2. The total R&D agreements have a positive and significant effect on patents. This is consistent with the findings in Section 5. And the R&D spending variable is positive and nearly significant. But none of the other factors have significant coefficients.[92] Moreover, the signs on most of the other coefficients are not as predicted by the hypothesis: the mutual learning focus coefficient is negative, the opportunism coefficient is positive, the organizational learning index is negative, the top down index is positive, and the internal information quality is negative. If these were all significant, they would largely invalidate the hypothesis.

Thus, this profits model confirms the findings in Section 5 without further support for Hypothesis 2.

ANALYSIS OF HYPOTHESES 3, 4 AND 5: THE IMPACT OF EXECUTIVE ATTITUDES, COMMUNICATION QUALITY AND ALLIANCE EXPERIENCE ON ALLIANCE PERFORMANCE AND NEW ALLIANCE FORMATION

Hypotheses 3, 4 and 5 explore the effect of external organizational learning (or information acquisition) variables on alliance performance and formation. With one exception, the three models use the same set of independent variables.

[92] This may be due to several factors. One, the survey data are somewhat limited. Of the 74 responses, 62 are usable for the profits regression. Two, the intervening factors between alliances and profitability discussed above make the correlation of alliances and profits tenuous. The most significant third factor is a problem for both tests under Hypothesis 2. While the independent attitude, communication and organizational learning variables measure current conditions, the outcome variables are historical figures: patents are the 5-year total and profits are a 3-year average annual amount.

If one assumes that attitudes and organizational design are relatively constant over time, this may not affect the causality in a significant way. However, unavoidable error and uncertainty are introduced by this feature of the research design.

Three new independent variables and one new dependent variables are used to test Hypothesis 3.

Dependent Variables

The three new independent variables used for testing these hypotheses are the perceived success index, the perceived transaction cost problems index and the number of new (SDC) R&D agreements.

Success Index. The Success Index measures the perceived level of success the firm has had with alliances with firms from the three major trading blocs: U.S., Japan and Europe. The index is a normalized value of the total responses to question 8: "From your perspective, what has been the mean overall level of success of entity R&D alliances?" The index is created by summing the responses and dividing by 7 times the number of positive responses. As many firms form alliances only with firms from one or two trading blocs, it is necessary to normalize only according to the number of responses provided. Cronbach's alpha is a very high .99 indicating complete internal-consistency reliability.

Problem Frequency Index. This index measures the frequency of transaction cost problems the firm has experienced. It is the normalized total of the responses to question 11: "Please indicate the frequency of the following types of problems with alliances and consortia:..." The list includes the cost of negotiation and start-up, loss of employees to partners, failure of partners to give sufficient attention to alliance matters, loss of key data and business plans, etc. Cronbach's alpha is 0.80.

All SDC R&D Agreements (SDCALLRD). This is the total number of cooperative R&D agreements formed between 1985 and 1992 and is a measure of the current ongoing frequency of alliance formation.

Independent Variables

One new independent variable appears in these regressions, the total number of (CATI) R&D agreements. This variable is used only for the Hypothesis 5 test. The remaining independent variables were described above and used in the Hypothesis 2 test: mutual learning focus, opportunism focus, economics factors focus, external information quality and total R&D agreements.

CATI R&D agreements (CATRDAG): This is the number of R&D agreements of the firm recorded in the CATI database through 1989. The variable represents, for the most part, R&D agreements entered into before the agreements in the SDC database, whose strongest coverage begins in 1989. For the Hypothesis 5 test, the log transformation of CATRDAG is used.

Hypotheses 3, 4 and 5 Models

The following models are used to test Hypotheses 3, 4 and 5:

(1)

$$\begin{aligned}\text{Success Index} = {} & a_o + b_1\text{MutualLearnFocus} + b_2\text{Opportunism Focus} \\ & + b_3\text{EconomicFocus} + b_4\text{External - InfoQuality} \\ & + b_5\text{TotalR\&DAgreements} + e_r\end{aligned}$$

(2)

$$\begin{aligned}\text{ProblemFrequency} = {} & a_o + b_1\text{MutualLearnFocus} + b_2\text{Opportunism Focus} \\ & + b_3\text{EconomicFocus} + b_4\text{External - InfoQuality} \\ & + b_5\text{TotalR\&DAgreements} + e_r\end{aligned}$$

(3)

$$\begin{aligned}\ln(\text{NewR\&D Agreements}) = {} & a_o + b_1\text{MutualLearnFocus} + b_2\text{Opportunism Focus} \\ & + b_3\text{EconomicFocus} + b_4\text{External - InfoQuality} \\ & + b_5\ln(\text{CATIR\&DAgreements}) + e_r\end{aligned}$$

To disprove the hypotheses, the following significant coefficients are required:

Hypothesis 3:	Model 1: $b_1<0$		Model 3: $b_1<0$
Hypothesis 3A:		Model 2: $b_2<0$	Model 3: $b_2>0$
Hypothesis 4:	Model 1: $b_4<0$	Model 2: $b_4>0$	Model 3: $b_4<0$
Hypothesis 5:	Model 1: $b_5<0$	Model 2: $b_5>0$	Model 3: $b_5<0$

The Economic Focus variable is not one of the predictors of the hypothesis. However, it is included as an important control variable and point of reference.

Hypotheses 3, 4 and 5 Descriptive Statistics and Correlations

Tables 6.6 and 6.7 show the summary statistics and correlations for the new variables used to test Hypotheses 3, 4 and 5. As mentioned

above, Cronbach's alpha for the mutual learning focus is low, as is its standard deviation.

Table 6.6

Descriptive Statistics of New Hypothesis 3 Variables

Variable	Mean	Median	75%quar tile	Maximum Value	SD	Cronbach's Alpha
Success index	.379	.429	.571	.881	.236	.99
Problem frequency	.392	.410	.50	.75	.145	.80
SDC R&D agreements	4.15	0.0	3.75	50.0	8.92	NA
CATI R&D agreements	3.05	1.0	3.0	29.0	5.65	NA

NOTE: Dependent variables are shown in the top block.

Table 6.10 presents the correlations for all of the variables used in the regression models, except the CATI R&D agreements variable used only in Hypothesis 5. As can be seen, while some correlation exists among the attitude variables (mutual learning focus, opportunism focus and economics focus), multicollinearity problems should be minimal as none of the other independent variable correlations is excessive.

Principal Components Analysis of Attitude Variables

Insights into the relationships among the executive attitude variables can be seen from the principal components analysis of the three variables. Principal component analysis is a method of explaining the variance and covariance structure using linear, orthogonal, combinations of the original variables. Principal components are linear combinations which maximize the sample variance. (Johnson & Wichern, 1988). These combinations are used both for data reduction and interpretation.

Table 6.7

Correlations for Hypothesis 3, 4 and 5

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Success index	1.0	-.03	.28	.11	-.17	-.01	.41	.31
(2) Problem frequency	-.03	1.0	-.16	.22	.31	.05	-.09	-.13
(3) SDC R&D agreements	.28	-.16	1.0	.20	-.11	.05	.15	NA
(4) Mutual learning focus	.11	.22	.20	1.0	.46	.44	-.05	.17
(5) Opportunism focus	-.17	.31	-.11	.46	1.0	.50	-.15	.11
(6) Economic focus	-.01	.05	.05	.44	.50	1.0	.13	.04
(7) External info quality	.41	-.09	.15	-.05	-.15	.13	1.0	.19
(8) Total R&D agreements	.31	-.13	NA	.17	-.11	.04	.19	1.0

As is clear from the Table 6.8, the three attitude variables load equally on the first component. On the second component, however, the mutual learning focus is positive while the other two are negative. And on the third, the opportunity focus is negative and the other two positive. These three eigenvector dimensions could be termed: (1) consideration of all the conditions and factors, (2) evaluation of the learning opportunities, and (3) contrasting the economic and learning opportunities with the threat of opportunism.

Table 6.8

Principal Components of Attitude Variables

Eigenvalue	1.935	.570	.495
Percent	64.50	19.00	16.51
CumPercent	64.50	83.49	100.00
Eigenvectors			
Mutlearnfocus	.564	.788	.247
Oppfocusindex	.591	-.177	-.787
EconFocus	.577	-.590	.565

The most important factor is the first component. Thus, most of the variance can be explained by relatively equal consideration of all opportunities, economic factors and threats of alliances. The remaining variance is due to contrasts among the learning opportunities, opportunism threats and economic considerations. Some of the variance is due to executives emphasizing learning opportunities over economic considerations and opportunism threats. The balance is explained by consideration of both the learning opportunities and economic factors in a positive light, in contrast to opportunism threats.

Table 6.9 shows the regression coefficients for the principle components substituted for the attitude variables in Table 6.5. All other coefficients have the same magnitudes, signs and significance as those shown in Table 6.5.

Table 6.9

Principal Component Regression Coefficients

	Log Sector Patents	Profits
All factors PC 1	.257** (.127) [29.6]	-6.53 (17.4)
Learning Only Focus PC 2	.315 $^{p=.16}$ (.220) [36.3]	-28.0 (31.4)
Learning and economic focus PC 3	.007 (.256) [.807]	-18.1 (35.0)

NOTE: Standard errors are in parentheses. Significance indicated by the asterisks: (*) p<.1, (**) p<.05, (***) p<.001, (****) p<.0001. Marginals are indicated within the brackets [ ].

As is clear from the principal component coefficients, a balanced consideration of the economic factors, learning opportunities and opportunistic threats is positively and significantly correlated with patent production. A learning only focus is also positive, of greater magnitude, and nearly significant. The third component has no

Table 6.10

Hypotheses 3, 4 and 5 Regressions Table

Dependent Variable	Success Index	Problem Frequency Index	New R&D Agreements Log SDCAll R&D
R^2	.38	.28	.56
Adjusted R^2	.32	.22	.52
Mean response	.37	.41	.88
Observations	65	67	66
Intercept	-.152 (.181)	.307** (.110)	-.528 (.728)
b_1 Mutual learning focus	.462* (.258)	.008 (.164)	2.46** (1.05)
Opportunism focus b_2	-.048 (.190)	.396*** (.116)	-1.60** (.785)
b_3 Economic focus	-.127 (.187)	-.062 (.117)	-.167 (.805)
b_4 External communication quality	.476**** (.100)	-.100$^{p=.12}$ (.063)	-.155 (.430)
b_5 Total R&D agreements	.003$^{p=.11}$ (.0017)	-.0011$^{p=.27}$ (.001)	
b_{5A} Log CATI R&D agreements			.777**** (.101) [.988]

NOTE: Standard errors are in parentheses. Significance indicated by the asterisks: (*) p<.1, (**) p<.05, (***) p<.001, (****) p<.0001.

significance (p=.98). Thus, a balanced consideration of all factors is most important. A learning focus is nearly as beneficial.

For the profits model, none of the components is significant or nearly so. The component with the greatest significance is the learning only focus with a p value of .38. Hence, attitude toward alliances is not a significant factor for profit outcomes.

Hypotheses 3, 4 and 5 Regressions

Tables 6.10 and 6.11 present the regression coefficients for the three models used to test Hypotheses 3, 3A, 4 and 5. All of these

regressions have been corrected for outliers by eliminating cases whose studentized residuals exceed the 2.0 cut-off magnitude.[93]

Results

Hypothesis 3

The *data support the hypothesis that firms whose executives focus more on mutual learning opportunities of alliances form more alliances and perceive greater success with ongoing alliances.* The b_1 coefficient for Mutual Learning Focus in the Success Index model is positive and significant at the 10% level. In the New R&D Agreements model, the coefficient is positive and significant at the 5% level. Despite these results, the low variance of the responses to the Mutual Learning Focus questions make this finding tentative.

Hypothesis 3A

The data also support the hypothesis that firms whose executives focus more on the threats of partner opportunism form fewer alliances and perceive more transaction cost problems. The b_2 coefficient for Opportunism Focus in the Problem Frequency model is positive and significant at the .1% level. And in the New R&D Agreements model, the coefficient is negative and significant at the 5% level. Thus, *an executive focus on potential opportunism is correlated with lower alliance formation rates and higher perceptions of transaction cost problems with ongoing alliances.*

This strong finding is based on indexes with adequate variances and alpha values. Moreover, conceptually the model and hypothesis are just the reverse of the Hypothesis 3 model regressions. This suggests that better question design and data for Hypothesis 3 would yield comparable significant findings.

Hypothesis 4

The effect of communication quality from alliance partners is tested in Hypothesis 4. The regressions show that *better external communication quality is correlated with fewer transaction cost problems*

[93] The number of eliminated outliers are the following: Success Index (4), Problem Frequency Index (2), and New R&D Agreements (3).

and highly correlated with greater perceptions of success. It is not correlated with increased numbers of alliances.

The b_4 coefficient for External Information Quality is positive and very significant, at the .01% level, for the Success Index model. It is negative, and almost, but not, significant (p=.12) for the Problem Frequency model. These findings both support the hypothesis. But the coefficient is negative and non-significant (p=.72) for the New R&D Agreements model.

Thus, perceptions of success depend in large part on the perceptions of information quality received from alliance partners. The better the quality of that communication in terms of frequency, timeliness, usefulness and value for the innovation activities of the firm, the greater the perceptions of success. Follow-on research should separate these distinct determinants of communication quality.

Given the strong finding in the Success Index model, it is no surprise that low external communication quality is correlated at the 12% level with increased problem frequency. However, the non-significance of the correlation with new R&D agreements was unexpected. The lesson from the three models is that prior experience largely dictates the formation of new agreements, external communication quality determines how successful alliances will be.

Hypothesis 5

The firm-based learning curve of alliance participation is tested in Hypothesis 5. The data show that *increased alliance experience has a positive effect on perceptions of success. Moreover, past alliance experience has a very strong impact on the formation of new alliances.* Increased experience is also negatively correlated with problem frequency.

The b_5 coefficient for total R&D agreements is positive and nearly significant (p=.11) for the Success Index model. It is negative and non-significant (p=.27) for the Problem Frequency model. In the New R&D Agreements model a variable for prior R&D agreements, the natural log of the CATI R&D agreements, is used. The regression coefficient for this variable is positive and very significant at the .01% level.

Thus, alliance experience has a very strong influence on the formation of new agreements. This in itself suggests the validity of the experience curve hypothesis for alliance participation. The positive effect of experience on perceptions of success, and negative influence on problem frequency, provides further support for the hypothesis.

Principal Components Analysis of Hypotheses 3, 4 and 5

Table 6.11 shows the coefficients for the principal component variables substituted for the attitude variables in the Table 6. 10 regressions. As before, all other coefficients for the regressions are unchanged.

Table 6.11

Principal Component Regression Coefficients for the Table 6.10 regressions

	Success Index	Problem Frequency Index	New R&D Agreements
All factors PC 1	.012 (.017)	.031** (.010)	-.013 (.067)
Learning only focus PC 2	.049 p=.104 (.030)	-.005 (.019)	.257** (.124)
Learning + economic focus PC 3	.007 (.032)	-.052** (.020)	.240* (.138)

NOTE: Standard errors are in parentheses. Significance indicated by the asterisks: (*) p<.1, (**) p<.05, (***) p<.001, (****) p<.0001. Marginals are indicated within the brackets [].

These coefficients indicate that success is significantly affected by the learning only component (but the magnitude is small, about a tenth of the mutual learning focus in Table 6.10). A consideration of all factors is positively and significantly correlated with a positive perception of problems, while consideration of economic and learning factors is negatively and significantly correlated. These coefficients are also of small magnitude. But for the new R&D agreements model, the second and third components are both significant and of comparable

magnitude. Thus, the balance of considerations have minor effects on perceptions of success and problems, but comparable positive effects on the formation of new agreements.

SUMMARY

The organizational learning factors tested in Hypothesis 2 are clearly correlated with patent production. However, other than the total R&D agreements, they are not correlated with profitability.

The external organizational learning factors tested in Hypotheses 3, 4 and 5 generally have the predicted impacts:

- Firms whose executives focus more on mutual learning opportunities of alliances form more alliances and perceive greater success with ongoing alliances.
- An executive focus on potential opportunism is correlated with lower alliance formation rates and higher perceptions of transaction cost problems with ongoing alliances.
- Better external communication quality is correlated with fewer transaction cost problems and highly correlated with greater perceptions of success.
- Increased alliance experience has a positive effect on perceptions of success. Moreover, past alliance experience has a very strong impact on the formation of new alliances.

Despite the general findings for the mutual learning focus and opportunism focus, the principal components analysis of the three attitude variables indicates that most of the variation among the three attitude dimensions is explained by consideration of all factors, economic, learning and opportunism. Nevertheless, the second component appears to influence patent production, perceptions of success, and the formation of new agreements. And a learning focus coupled with consideration of economic factors is negatively correlated with the occurence of alliance problems. Thus, among surveyed executives the learning perspective appears to be an extension on traditional competitive business practice.

7. DISCUSSION, CONCLUSIONS AND POLICY IMPLICATIONS

This report commenced by outlining the trends in policy and corporate practice toward increased cooperation. The public policy community has recognized the importance of technical cooperation among firms and government entities; economic theories have begun to realize the complexity of the innovation process and the benefits of cooperation; and organizational learning theories, that have gained favor in recent years, contemplate increased levels of communication and cooperation in the innovation process. Moreover, during the last several years, the frequency of corporate research alliances has accelerated. The cumulative density of such alliances has grown rapidly.

Historically, the primary impediments to increased research collaboration have been anti-trust policies and enforcement efforts. While these have been restrained in recent years and curtailed by specific legislation opening the way to research cooperation, in 1994 the Anti-Trust Division of the U.S. Justice Department spearheaded renewed anti-trust enforcement rhetoric and efforts.

Before drawing policy implications regarding these trends, I will summarize the empirical findings of this research. These will be discussed at the aggregate level. The sectoral influences which must be understood when planning firm-level policy and strategy will not be discussed here.

DIRECT FINDINGS AND CONCLUSIONS

This research produced four general findings and a variety of subsidiary results.

First, cooperative research alliances do have a positive impact on patents and profits. But this must be qualified. International cross-trading-bloc alliances positively influence both patents and profits. Domestic alliances have a positive impact on patents, but a negative impact on profits. In the E.U., trading-bloc-only European alliances have a slight negative correlation with patents but a strong negative

impact on profits. Thus, the net finding is that *international alliances, in general, positively affect patents and profits.* For domestic and E.U.-only alliances, the impacts are mixed.

As suggested by interviewed executives, a portion of the international alliance and patent correlation may be due to defensive patenting. While this could not be proved or disproved, the weight of the empirical evidence appears to counter defensive patenting as a solitary explanation. For one thing, the research data are clear that the influence of alliance formation on patents is several-fold larger than that of patents on alliances. But the data, in their present form, are incapable of showing the exact time series lags and correlations.

Second, the influence of communication linkages and flows on innovation is generally positive. As shown in the tests of Hypothesis 2, the quality of external information flows has a positive, significant and potentially large impact on patent production. It is also positively, but non-significantly, correlated with profits. However, as measured by the limited questionnaire, internal information flows and the degree of internal R&D organizational integration have mixed, but non-significant, impacts on patent production. But as shown in the tests of Hypothesis 3, external communication quality has a significant positive impact on perceptions of alliances success and a negative impact (p=.12) on the perceptions of transaction cost problems.

Third, the index of organizational learning has a large, positive and significant impact on patent production. Moreover, executive attitudes, alliance frequency, and communication flows all contribute to the organizational learning capability of innovating firms. Executive attitudes set the tone for alliance relationships, alliances appear to provide new sources of technology-based and customer-based information. And communication flows convey this information. And the degree of internal organizational learning design contributes to the information processing capability of the firms.

On the other hand, the organizational learning index is negatively, but non-significantly correlated with profits (p=.67). This may be explained by several factors. Organizational learning practices may lead to a greater focus on learning new technologies than on competing

profitably in the market place. Or, such internal firm practices may engender too much trust in external cooperative relationships, leading to lost technology and competitive advantage. The more likely explanation may be that firms with losses are more open to change and are adapting organizational learning practices more rapidly than firms with profitable market positions. A final possibility is that profitable firms have become more adept at searching, evaluating and processing technological information, and delivering profitable products, regardless of the degree of organizational learning practices measured by the questionnaire. In other words, the actual overall degree of organizational learning of the firm due to market experience exceeds what the questionnaire evaluates.

The fourth conclusion is that executive attitudes appear to make a difference. A mutual learning focus on the learning potential of alliances has a positive impact on the formation of alliances, the perceptions of success and the rate of patent production, but not on the profitability level. The correlation of the learning orientation with profits is negative, but non-significant. A focus on the threat of opportunism is strongly correlated with the perception of transaction cost problems.

Thus, attitudes do influence alliance behavior and success. But executives would be ill advised to form alliances focused only on the learning opportunities. As implied by the principal components analysis of the three attitude variables, Table 6.8, all three variables are important. The largest variance of executive attitude can be explained by an equal weighting of the possible mutual learning benefits and opportunism risks, along with the economics factors.

Finally, experience counts. In general, the more firms have been involved in cooperative R&D agreements, the greater their perceptions of alliance success, the fewer problems arise, and patent production is significantly higher, as are profits. In addition, prior experience with alliances is strongly correlated with the formation of new alliances. In fact, prior alliance experience is the strongest predictor of alliance formation and patent production. In addition,

experience is negatively, but non-significantly, correlated with an opportunism focus.

Together, these findings appear supportive of the resonant organizational learning theory. Increased external connections and communication flows do enhance the innovation learning process. And to one degree or another, internal information flows, and organizational learning designs appear to contribute to the innovative learning.

The findings also help explain the accelerating trend of alliance formation. As firms become more experienced with alliances, they apparently realize the benefits, learn to manage cooperative relationships, avoid the pitfalls and make cooperative strategies a key element of corporate innovation policy. The data show that firms on the leading edge of technological innovation tend to engage in multiple alliances.[94] These require efficient communication channels and high levels of partner trust. Developing these to the required degree makes further research alliances easier to establish and manage. In other words, as indicated by the Hypothesis 5 tests, firms go down a cooperative alliance learning curve.

One could say that the technological learning capabilities of alliance-active firms are enhanced by their alliances. As suggested by Rittel (see Appendix C) the time to market with new products may decrease for cooperating firms. The net societal result, according to Link's model (also in Appendix C), may be increased basic research.

In this complex web of alliance relationships, executive attitudes, communication flows and organizational learning practices, other explanations for the data and findings are certainly possible. The positive impact of alliances on patent output and profitability may decrease as more and more firms join what appears to be the alliance bandwagon. So these could be transitory effects or first-mover effects. In addition, the limited scope of the mailed project questionnaire may have been inadequate to assess the actual impact of organizational learning practices, communication quality, and executive attitude. The

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[94] For example, see Figure 5.4, and Tables 5.8 and 5.11.

complexity of the relationships is implied by the principal component analyses. Certainly, they merit greater in-depth study.

On the other hand, most of these results are consistent with the organizational learning theories and emerging business practices. And at the aggregate level, they are sufficient to draw tentative conclusions for technology policy.

Of particular interest are the complex sector differences for the relationships studied here. The executive interviews provided a glimpse of the possible explanations for the variation across the sectors. These differences may be important for policy development and are crucial for corporate level strategy. One possible future research project would categorize the various sectors according to the degree of domestic and international competition, rate of underlying technological change, economies of scale, level of national subsidies, etc., and determine how those factors affect the alliance-performance correlations explored in this research.

PROBLEMS WITH THE RESEARCH AND SUGGESTIONS FOR ADDITIONAL RESEARCH

The single most serious problem with the research is the need for more questionnaire and financial data, particularly R&D data. This can be addressed by additional research resources for data acquisition. As published R&D data are scarce, surveys may be the best source. However, a key element for obtaining data by survey is securing executive cooperation. The perceived benefits of survey participation must be seen to outweigh the costs in time or the risk of leaked confidential information. In many cases, confidential information will be released only with binding confidentiality agreements. While RAND's unilateral confidentiality promise in the questionnaire solicitation materials was adequate to elicit responses, in some case this promise did not provide sufficient protection.

One possible strategy would be to build on the results of this research. As became clear when I followed-up on my first questionnaire mailing, executive interest is motivated by results. When I suggested the emerging correlations in my follow-up fax, the response rate nearly

doubled. Several executives called to see if it was too late to participate.

Thus, an additional project could be designed to fully explore the cooperative dynamics of a particular sector, say semiconductors. Research executives could be given the summary results of this research and asked to assist in improving the insights into the alliance dynamics. The solicitation should include a signed confidentiality agreement for consideration and execution by the firm.

A second problem is that the sample frame was not a random sample of the entire population of innovating firms. Rather the focus was on three sectors. And as the analysis indicated, there are clear distinctions among the sectors. Hence, the aggregated results of the research may not be representative for the entire economy, or any sector in particular. However, the sectors chosen are three of the most important industrial sectors, in terms of technology, revenue streams and innovativeness.

My intent was to sample the entire population of innovating firms within the research sectors. But published financial data are generally available only for public corporations. So privately held firms are not included in the Hypothesis 1 test. This should not be a major problem as most automotive, semiconductor and aerospace firms spending more than $1 million annually on R&D are public corporations.

On the other hand, the questionnaire response bias was a potential problem. As explained in Section 4, the size and innovativeness of the responding firms were significantly larger than the average for the sample frame. Nevertheless, for purposes of making public policy inferences, this may not be detrimental. If alliances are beneficial for larger firms with established R&D departments and technology, they may be beneficial for small firms attempting to develop new technologies and gain market share.

One particularly difficult problem is the assignment of patents, alliances and financial data when subsidiaries are involved. CHI Research assigns patents to the parent firm. The CATI and SDC databases assign alliances to the firms mentioned in the announcement of the

alliance. Financial data are generally consolidated in the parent's Securities and Exchange Commission (SEC) disclosure.

So if a subsidiary is performing all innovation research, alliance partnering and production in a particular sector, but its financial results are aggregated and reported under the parents' name, accurate analysis is impossible. The problem is made more difficult when research occurs at the corporate parent level, while product development, manufacturing and marketing occur at the subsidiary level.

The simplifying assumption made for this research is that a parent's patents and alliances for the sector under analysis are attributed to the subsidiary specializing in the field.

Another problem is that the categories of domestic, trading-bloc-only, and cross-trading bloc do not capture all possible variations or impact of corporate cooperation. For example, two firms from the same country may form a domestic alliance to access the international suppliers, allies and customer base of each other, or compete together in international markets. Obviously, the data are not sufficiently detailed to make these distinctions. However, such a bias, to the extent it exists, would indicate greater significance for the computed domestic alliance coefficients. This, in turn, would strengthen the unbiased strength of international alliances.

As the international alliances already have the major significant correlation with patents and profits, this possibility does not weaken the reported results. However, the general observation that the tri-part categorization does not capture all possible variations of alliances is valid. For example, some of a firm's alliances may be more important than others. And this weighting is not reflected in the data.

A final problem concerns the multiple regression method of analysis. As is implied by Section 3 and becomes clear in Section 4, this research tested many interrelated influences and outcomes. To sort out all of the cause and effect relationships, some form of path analysis may be required. However, such analysis would best be done on data from a single sector to eliminate the industry specific influences.

POLICY IMPLICATIONS

Several implications of this research for government policy are worth highlighting. However, these implications should be treated with considerable caution because policy level inferences cannot be confidently drawn from corporate level data and analysis. Moreover, the possibility of defensive patenting weakens the inferences somewhat. Nevertheless, on balance the findings appear sufficient to warrant the following inferences.

First, anti-trust enforcement that attempts to disrupt cooperative research and development, as a way of enhancing competition, may be counterproductive. The most serious unintended consequence may be to limit the innovation rates and capabilities of domestic firms. For example, according to this research, international alliances enhance innovation rates. Thus, restrictions on private-sector international R&D alliances would tend to slow the rate of innovation.

Government subsidies for research and development may not overcome the losses caused by enforced corporate individualism. As suggested by the background research (see Section 2), innovation apparently springs far more from the collective flow of ideas, insights and customer feedback than from separate research efforts, even when supported by government largesse. The loss of the semiconductor market by the insular European manufacturers to the cooperating U.S. and Japanese competitors should be sufficient warning of the chilling effect of restraints on cooperative innovative activities.

Second, public policy should recognize the importance of international research cooperation for opening new markets, providing expanded customer inputs into the innovation process and accessing and developing new technologies. The significantly positive coefficients for international cooperative agreements in the patent production and profit regressions are the strongest finding of this research. One important reason for these findings may be that innovation is a networked learning process, and customer and market feedback is therefore crucial for innovation. Hence, cooperative research flows may be as important for increased innovation, as is free trade for global prosperity.

Therefore, except in cases where national security concerns are predominant, the strong inference is warranted that neomercantilist policies, which seek to stimulate the creation of unique domestic technological capabilities, should be replaced by transnational policies, which encourage international engagement in technology development, as well as trade.

The implications of this research are consistent with the recent passage of GATT in the United States. But they caution against viewing the global technology marketplace as a zero-sum game. Instead, the findings support the development of U.S. policies supportive of science and technology cooperation at all levels. Not only might such policies foster increased rates of innovation and decreased innovation cycle times[95]; they may also enhance global technological diffusion and customer learning, which in turn can fuel economic demand and provide important feedback of further innovation possibilities.

Some insight about the relative benefits of research subsidies and alliance participation can be drawn from the patent productivity regressions in Table 5.19. From that table it is clear that R&D spending (relative to alliance effects) is, in all cases except for the automotive sector, negatively correlated with patent productivity. Similarly, in the same majority of cases, cross-trading-bloc R&D agreements are positively correlated with patent productivity. And in the innovative semiconductor sector the negative R&D spending coefficient and the positive cross-trading-bloc coefficient are very significant. Thus, the table shows that for the semiconductor sector, subsidies for R&D may not generate additional innovation, and certainly not to the degree of additional cooperative international alliances.[96]

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[95] See Rittel's models of cooperative innovation in Appendix C.

[96] The sector differences may be due to the relative degree of global competition in each of the three sectors. In the automotive sector, the intense global competition may mean that sufficient trust for successful research alliances rarely develops. On the other hand, in the aerospace and semiconductor sectors, new innovations are so difficult to develop (aerospace), or are occurring so rapidly (semiconductors) that alliances contribute far more to the requisite technological learning than does additional in-house R&D spending.

Additionally, the theoretical analysis suggests, and the empirical data do not disagree, that the rate and quality of communication flows are important innovation factors. Prior research has shown that customers are one of the most important sources of communication flows. Together these findings suggest the possibility that trade laws, such as anti-dumping laws, which are intended to protect domestic industry, may be counterproductive because they disrupt customer feedback which would motivate innovation learning at the protected firms.[97]

Finally, all of these policy recommendations are based on inferences drawn from the cooperative experience of private firms. As indicated in Section 6, the research shows that firms forming alliances benefit from prior alliance experience. The implementation of national policy is probably not different. Thus, while the implications of this research analysis are that transnational and cooperative policies should be adopted widely by the government, a go-slow approach is probably best, because it can facilitate the acquisition of experience which, in turn, will generate future alliances.

One way to proceed would be to articulate widely the cooperative objective, particularly in the context of the new GATT. A mutual learning focus for technology, trade and international anti-trust policies that affect cooperative research could be simultaneously incorporated. But such focus should be coupled with a healthy awareness of economic realism and strategic opportunism. Thus, implementation of cooperative trade and anti-trust policies should probably be phased in over time as experience is obtained and the global political environment adjusts to increasingly higher levels of commercial and public cooperative alliances. Nevertheless, reconsideration of anti-trust policies that threaten ongoing and planned cooperative R&D activities should not be delayed.

[97] For a comentary on the importance of free flowing trade for innovation, see Lewis (1993).

Appendix A

RAW REGRESSIONS, LEAST-SQUARES ERRORS, AND THE BENEFITS OF LOGARITHMIC TRANSFORMATIONS AND THE ELIMINATION OF OUTLIERS

This appendix presents the results of the Section 5 analysis using untransformed variables, the resulting deviation from the assumptions of least-squares regressions, and the requisite transformations.

PATENT REGRESSIONS

Table A.1 summarizes the regressions using the four models shown in Section 5 using untransformed variables.

Table A.1

Sector Patents Regressions

Dependent Variable: Sector Patents	Model 1	Model 2	Model 3	Model 4
R^2	.55	.52	.64	.53
Adjusted R^2	.54	.51	.64	.52
Mean response	87.5	77.9	87.5	77.9
Observations	300	146	300	146
Intercept	-9.3	4.3	-5.2	3.82
	(12.1)	(15.3)	(10.9)	(15.1)
TOTRDAG	13.3****	9.40****		
	(1.11)	(1.29)		
AV3YRSALES	.006****	.0004	.004****	-.0006
	(.001)	(.0019)	(.001)	(.002)
AVRD8892		.101**		.122**
		(.036)		(.037)
AllDOMRD			-4.2*	2.6
			(2.21)	(3.30)
AllTBORD			-1.3	
			(6.17)	
AllXTBRD			36.0****	19.6****
			(2.79)	(4.92)

NOTE: Standard errors are in parentheses. Significance indicated by the asterisks: (*) p<.1, (**) p<.05, (***) p<.001, (****) p<.0001. Model 4 has no entry for ALLTBORD as the firms in the sample are only U.S. firms which have no such trading-bloc agreements.

The regressions in Table A.1 show clearly that research and development agreements have a strong positive, and highly significant, impact on patent output in both Models 1 and 2. Moreover, Models 3 and

4 show that research agreements which cross trading-bloc boundaries have the strongest impact. In Model 3, domestic agreements have a negative impact on the dependent variable, significant at the 10 percent level (p value equals .06). Trading-bloc-only agreements have virtually no impact. Although the sign on the AllTBORD coefficient is negative, the p value is very high (.84). In Model 4, domestic agreements have a positive, but non-significant impact. Model 4 is evaluated using the 148 U.S.firms in the sample for which I have R&D data.

Discussion of Analysis Errors

The validity of multiple regressions, on which this analysis is based, depends on several assumptions about the normality of the data and the error terms in the basic linear relationship.

$$y_i = \alpha + bx_i + u_i$$

1. The mean of the error terms, u_i, is zero for all i.
2. The variance for all error terms is common. $\mathrm{var}(u_i) = \sigma^2$.
3. Independence of error terms. u_i and u_j are independent for all i not equal to j.
4. Independence of x_j. u_i and x_j are independent for all i and j. In other words, the distribution of u does not depend on the value of x.
5. Normality. u_i are normally distributed for all i. (Maddala, 1988).

Normality. Probably the most important assumption of linear regression is the normality assumption. It must be satisfied in order to draw valid statistical inferences. To test for normality, one looks at a normal quantile plot of the residuals (Figure A.1).

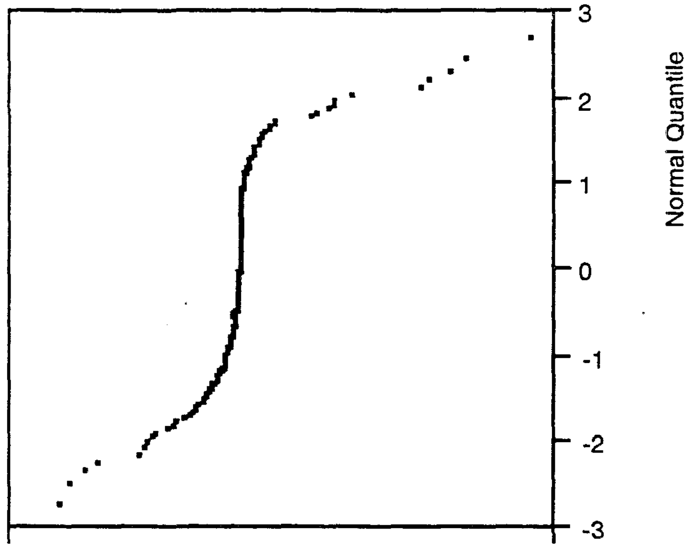

Figure A.1—Normal Quantile of Model 1 Regression Residuals

A normal distribution on a normal quantile plot is a straight line from the lower left to upper right corners. This plot of the Model 1 regression residuals with untransformed variables clearly indicates that the distribution of the residuals does not satisfy the normality assumption.

Heteroskedasticity. If the second assumption, the homoskedasticity assumption of common variance, is violated, the regression suffers from what is known as a heteroskedasticity. The consequence of this condition is that while the least square estimators are unbiased, they are inefficient. Moreover, the estimates of the variances are biased, distorting or invalidating the tests of significance.

The sector patent regressions also appear to have a partial heteroskedasticity problem. This can be seen by the distribution of the residuals as a function of the predicted Y value. Figure A.2 shows the potential problem, the linear boundary along the bottom left side of the distribution. A classic heteroskedasticity problem is recognized on such a plot as a "<" shaped distribution. In addition to this partial "<" shaped distribution, it is clear that the variances across the predicted values are not uniform: the variance at the left side is

substantially less than on the right side of the distribution of residuals.

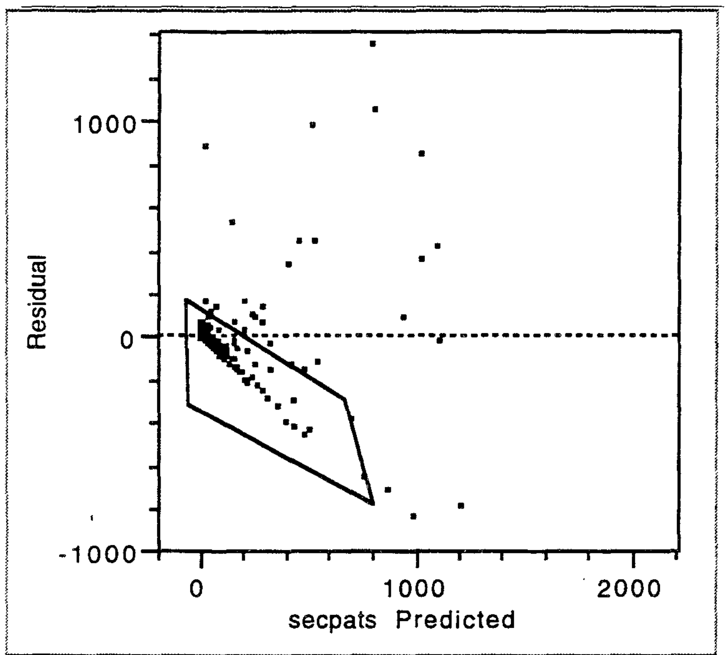

Figure A.2—Possible Heteroskedasticity Problem with Sector Patent Regression

Examination of the cases along the lower left boundary indicates that these include firms which have no alliances and no sector patents. They were retained in the sample frame because the firm obtained one or more total patents, but they have no sector patents, the primary output variable used in the analysis. The cases along the far bottom right of the boundary have alliances, but no sector patents. And a few have both alliance and patents, but far fewer patents than would be predicted by their alliance activity.

The recommended solution for heteroskedasticity is to use weighted variables in doing the analysis. The most common weighting is to convert all variables to logarithms. Such a method also has the virtue of normalizing the distribution of the variables themselves, and may correct the normality of residuals condition.

Thus, for the patent variables the indicated transformations are logarithm conversions.

Discussion of Analysis Errors

The regressions of the transformed variables show much improvement in consistency with the assumptions of least square regressions. Figure A.3 shows the improved normality of the residuals. Compare it with Figure A.2.

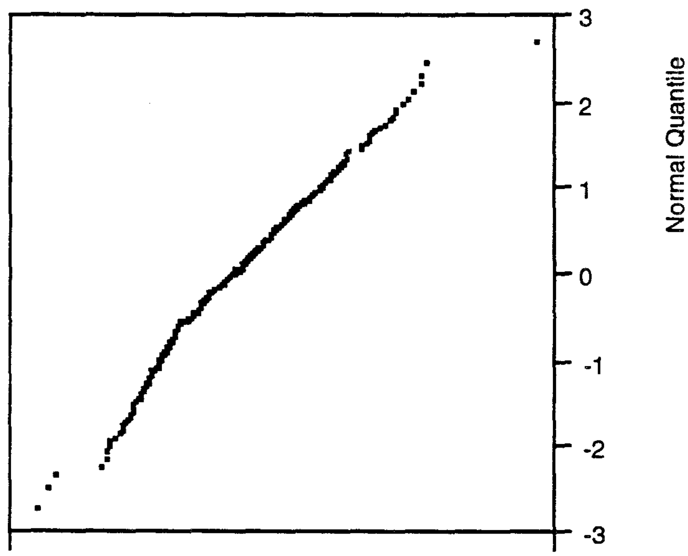

Figure A.3—Normal Quantile Plot of the Regression of Transformed Variables, Model 3

In addition to improving the normality of the residuals, the log transformation improves the homoskedasticity of the residual variances as shown by the Figure A.4.

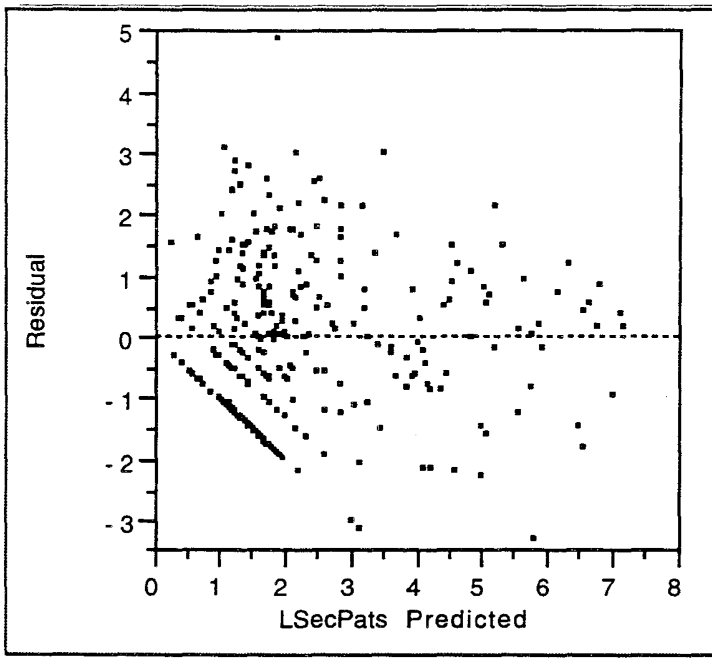

Figure A.4—Residual Plot of Transformed Regression, Model 3

As can be seen, except for the boundary row on the bottom left, the residual plot appears well behaved. The boundary primarily consists of firms for which the dataset contains no alliances or no sector patents, or in some cases none of either. The only way to eliminate this problem completely would be to delete these observations from the analysis. But since these observations do provide some additional information, I opted to retain them for the remainder of the analysis.

Also, because regressions using the log transformed variables have residuals with substantially better normality and less heteroskedasticity, I chose to perform the patent analysis using log transformed variables.

PROFITABILITY REGRESSIONS

The following tables and analysis shows the profitability analysis on the entire raw data set and the errors present in the models.

Table A.2 shows the regressions of average three-year profits on the alliances, with average three-year sales controlling for size effects.

Table A.2

Profitability Regressions for all firms using raw data

Dependent Variable: Average 3-Year Profits	Model (1)	Model (2)	Model (3)	Model(4)
R^2	.23	.52	.29	.55
Adjusted R^2	.22	.51	.28	.53
Mean response	90.4	73.0	90.4	74.0
Observations	302	148	302	148
Intercept	4.44	12.1	10.5	10.1
	(24.4)	(32.1)	(23.6)	(31.3)
TOTRDAG	-2.25	9.33***		
	(2.24)[a]	(2.72)		
AV3YRSALES	.017****	.046****	.016****	.043****
	(.002)	(.004)	(.002)	(.004)
AVRD8892		-.886****		-.829****
		(.077)		(.077)
AllDOMRD			-18.6****	-9.81
			(4.82)	(7.07)
AllTBORD			-58.1****	
			(13.4)	
AllXTBRD			23.0***	38.3***
			(6.07)	(10.23)

NOTE: Standard errors are in parentheses. Significance indicated by the asterisks: (*) p<.1, (**) p<.05, (***) p<.001, (****) p<.0001. Model 3b has no entry for ALLTBORD as the firms in the sample are only U.S. firms which have no such trading-bloc agreements.

[a]p value is .314.

The first obvious aspect of these uncorrected regressions is that the coefficient on TOTRDAG is negative, meaning that more agreements lead to lower profits. But the coefficient is not significant (p value = .314). More importantly, research and development expenses are moderately correlated with a firm's propensity to form cooperative research agreements as measured by TOTRDAG (correlation coefficient = .54). When the R&D spending variable is added as an independent variable (Model 2), the R^2 value more than doubles, even though the

number of observations is cut in half, and the negative sign on TOTRDAG becomes positive, and significant.

Model 2, of course, applies strictly to U.S. firms in the sample frame. However, since the signs and magnitudes on the AllDOMRD and ALLXTBRD variables in the regressions for Models 3 (All firms) and 4 (U.S. only firms) are comparable, one can infer that average profits are positively affected, in the aggregate, by the total research agreements a firm has formed during the prior 10-15 years. Thus, the first hypothesis is supported.

Most interesting are the regressions for Models 3 and 4. These indicate clearly that domestic and trading-bloc-only research agreements have negative impacts on profits, while cross-trading-bloc agreements have a strong positive impact. Clearly, while some of the negative impact shown in Model 3 may be due to the influence of R&D spending, Model 4 shows that controlling for R&D spending (and limiting the sample to U.S. firms) strengthens the impact of cross-trading bloc agreements.

Discussion of Analysis Errors

Examination of the residuals from the profitability regressions shows clearly that error terms are not normally distributed. This is primarily due to the widely skewed variation, both positive and negative, in the outcome variable, 3-year average net income. Unfortunately, there are no transformations that can stabilize the variance of distributions with widely varying positive and negative values.[98] This leaves two possible approaches. The first is to eliminate the outlying observations from the regressions. The second is to analyze only those cases with positive Y values, using log transformations to stabilize the variance.[99] With the first approach, the outliers must be chosen carefully, and will vary depending on the model. (Weisberg, 1985). The problems with the second approach are (1)

[98] One cannot take a logarithm or square root of a negative value. And the usual strategy for negative values (adding a small positive constant to all data points) won't work when the magnitudes of the negative values are large.

[99] This method was suggested for difficult nonlinear relationships by Weisberg. (Weisberg, 1985).

the relationships may vary for positive and negative outcome variables, and (2) even if the underlying relationships are indeed linear across the data set, the technique potentially eliminates substantial information about that relationship.

Figure A.5 shows the non-normality present in the residuals of Model 3 of the profitability data.

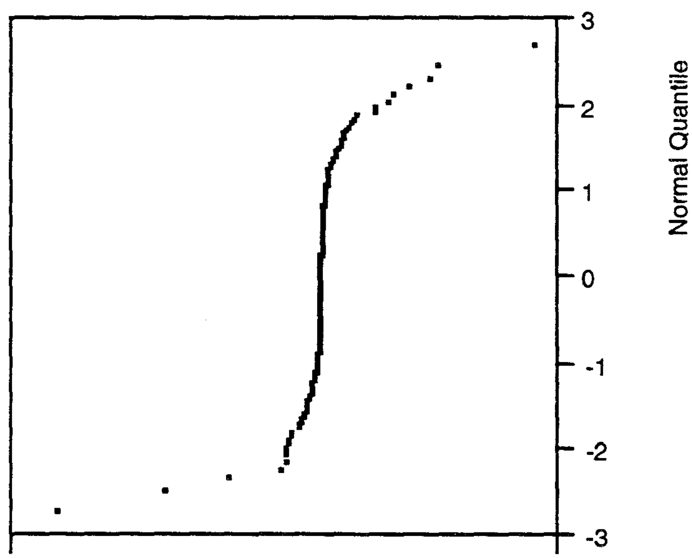

Figure A.5—Non-Normality in Profitability Data, Normal Quantile Plot

NOTE: 300 observations using Model 3.

The extreme spread in the residuals is clear from the following residual plot of the Model 3 regression, shown in Figure A.6.

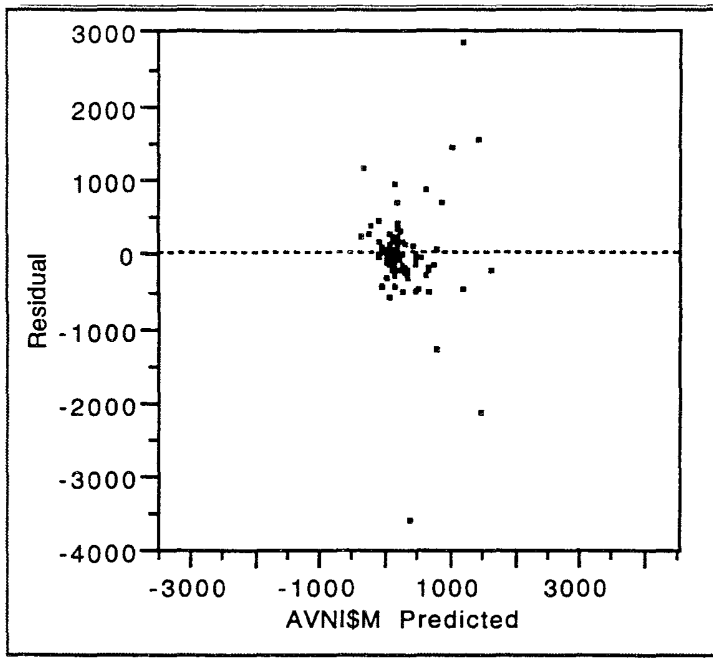

Figure A.6—Non-Common Variance in Residual Plot of Model 3 Regression of Profitability Data

As explained in the Section 5, eliminating outliers is best performed by examining the studentized residuals, and eliminating those observations with high values, over 2.0. (Draper, 1991; Weisberg, 1985). A studentized residual is a measure of the divergence of a point observation from the regression line, without the influence of the point itself. In other words, it is the residual standard deviation from the regression line with the observation itself temporarily set aside.

Figures A.7 and A.8 show the normal quantile plot, and residual plot for the Model 3 regression after elimination of the outliers. As can be seen, while not ideal, the normal quantile plot is closer to the desired diagonal, and the distribution of the residuals has a nearly uniform variance.

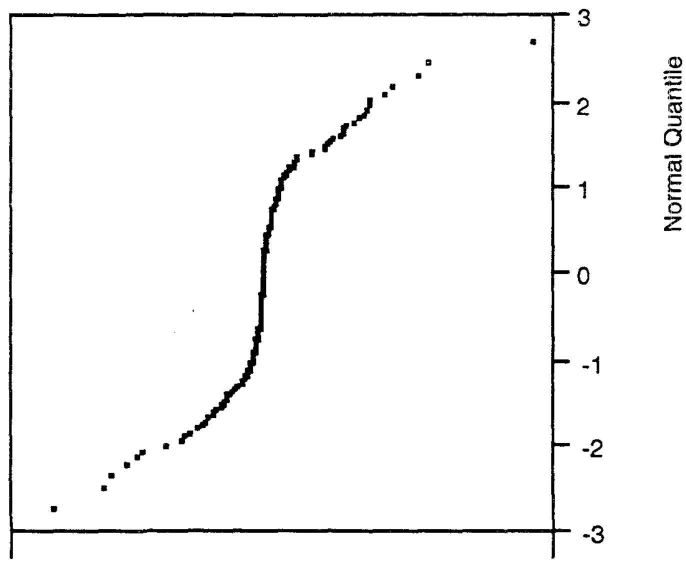

Figure A.7—Normal Quantile Plot for Model 3 After Elimination of Outliers

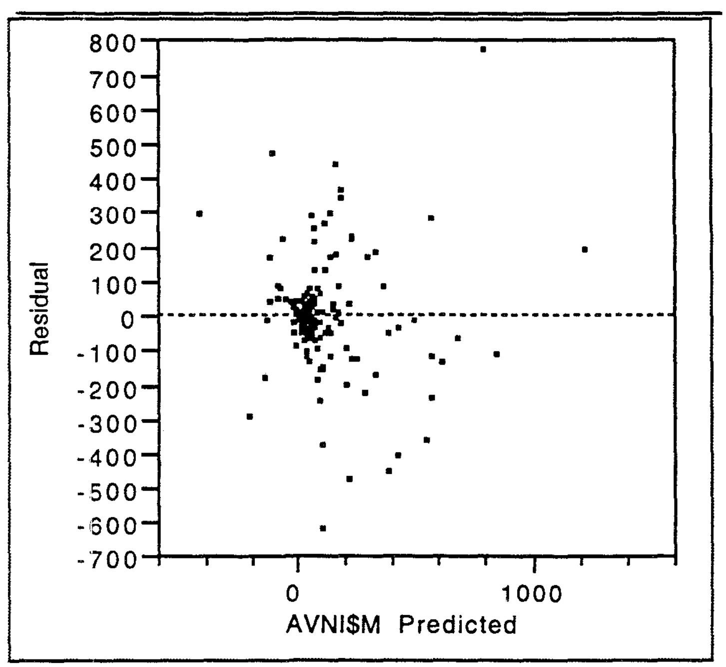

Figure A.8—Residual Plot for Model 3 Regression After Elimination of Outliers

Appendix B

OUTLIERS DELETED FROM REGRESSIONS

Note that the specific outliers deleted depend only on the studentized residual value as described in the text. They vary from regression model to model.

Table 5.13

	Studentized Residual |SR| > 2.0
Model 1	
Boeing	2.74
General Electric	8.56
Ford	-6.39
General Motors	-9.52
Toyota	4.63
Philips NV	-2.13
AT&T	3.85
H-P	2.12
IBM	-4.20
Model 2	
Boeing	2.55
General Electric	6.93
Chrysler	-2.52
Ford	-8.82
Texas Instruments	-2.00
AT&T	6.19
Note: GM was not eliminated SR=.43	
Model 3	
Boeing	2.47
General Electric	8.19
Ford	-6.42
General Motors	-9.76
Peugeot	2.76
Renault	2.05
Toyota	4.56
AT&T	4.21
H-P	3.99
IBM	-3.73
Model 4	
Boeing	2.15
General Electric	6.50
Chrysler Corp.	-2.01
Ford	-8.78
Texas Inst.	-2.07
AT&T	6.37
H-P	4.28

Table 5.15

Aerospace	
British Aerospace	-2.69
Fuji Heavy Ind.	-2.23
McDonnell Douglas	-3.14
General Electric	7.41
United Technologies	-4.54
NEC Corp	-3.27
Thomson CF	2.20

Automotive	
Chrysler	6.04
Ford	-4.24
General Motors	-6.34
Nissan	2.52
Toyota	4.45

Semiconductor	
AT&T	6.43
H-P	3.86
IBM	-8.03
Matsushita	2.83
Unisys	-2.61

Table 5.16

Aerospace	
General Electric	6.12
McDonnell Douglas	-4.65
United Technologies	-3.95
Westinghouse	-2.31

Automotive	
Cummins Engine	-3.18
Chrysler	-3.68
Ford	4.46
General Motors	-4.59
Phelps Dodge	2.60

Semiconductor	
AT&T	6.85
IBM	-6.98
H-P	3.44

Table 5.19

Entire Dataset	
Apple Computer	-3.31
Ford Motor	-2.10
Phelps Dodge	-2.19
Rogers Corp.	2.09
Westinghouse Electric	2.53

<u>Aerospace</u>	
McDonnell Douglas	-2.35
Mechanical Technologies	2.37
Westinghouse	2.77
<u>Automotive</u>	
Oshkosh Truck Corp.	-2.09
<u>Semiconductor</u>	
AMP Inc.	2.21
Apple Computer	-3.26
Brush Wellman	-2.19
Rogers Corp.	2.02

Appendix C

THE BENEFITS OF COOPERATIVE RESEARCH

The benefits of cooperative research include decreased time for innovation searches and problem solving, and increased resources for basic research. The arguments of two primary sources will be outlined here.

HORST RITTEL: HIERARCHY OR TEAM? CONSIDERATIONS ON THE ORGANIZATION OF R&D COOPERATIVES

In his seminal work (Rittel, 1965), Rittel outlined four examples of cooperative research and how they affected the time to develop new concepts. The following is based on the Rittel chapter. I paraphrase liberally. The figures are my own creation, but are based on those published by Rittel.

Simple Search for Single Correct Solution

If R&D is a search process consider the following search problems. The search space is a well-defined set of determinable but large number of alternatives, N. One and only one is to be chosen according to well-understood criteria. There are *r* persons (or firms). The issue is how the task is affected by having all *r* persons (or firms) participate:

1. Random selection of trials. Every participant selects one possibility. The process continues until the solution is located.

For this technique, the expected value or average number of trials necessary to reach the solution, T_r, is equal to: $T_r = \frac{N}{r}$ Obviously the savings in the number of trials is a time savings which, in the case of innovation, is crucial.

The relative savings of steps and therefore time, as compared to the steps needed for one person or firm working alone is $\frac{T_r}{T_1} \approx \frac{N/r}{N/1} = \frac{1}{r}$

2. Random selection but with memory. Possibilities already tried are not repeated. Results are stored as experience.

In this case, the number of trials is reduced by one-half, if N is very large as compared to ***r***. $T_r \approx \frac{N}{2r}$.

The relative savings of time (reduction in steps) is the same 1/r computed as follows: $\frac{T_r}{T_1} \approx \frac{N/2r}{N/2} = \frac{1}{r}$.

Thus, the amount of time to find the solution is proportional to the inverse of the number of participating individuals, or firms. However, the cost is the same whether the effort is allocated or not. $\frac{C_r}{C_1} = \frac{rcT_r}{cT_1} \approx 1$, where c is the cost of one trial, C_r is the cost where r persons or firms are used and C_1 is the cost when one person or firm is used.

In this simple case, the division of effort, or said differently, the cooperation of many on a single problem implies that the duration is inversely proportional to the number of participants and the total costs remain unchanged even if many share the work. But as time is a key cost and competitive advantage parameter in the real world, cooperation does imply dramatic savings.

Of course, the search example here is very simple. But (not shown by Rittel) where technological innovation solutions are sought in the real world, the cost of searching for and evaluating information will be less for the multi-person case. In that case, the cost relationship reduces to $\frac{C_r}{C_1} = \frac{c_{network}}{c_{individual}} << 1$, where $c_{network}$ is the cost of a single search when network resources are available. So savings are available with respect both to the cost and to time.[100]

Cooperative Problem Solving

Assume several individuals, or firms, which are attempting to solve a problem X. Assume that problem X can be subdivided into a sequence of k subproblems $X_1, X_2, \ldots X_k$. And these k subproblems must be solved sequentially. Let p_{ij} be the probability that person or firm A_i solves the partial problem X_j. Then the probability that A_i solves the entire problem alone is $p_i=p_{i1}*p_{i2}\ldots*p_{ik}$.

[100] This is my own extension on Rittel's ideas.

If we introduce cooperation so that *r* firms or individuals A_1, A_2,. . . .A_r are trying to solve the problem by working together, the probability of their solving the problem is:

$$P_r = \prod_{j=1}^{k}\left[1 - \prod_{i=1}^{r}\left(1 - p_{ij}\right)\right]$$

If all of the firms or individuals have equal abilities to solve the problem, then all the p_{ij} are equal. Then $p_{ij} = p^{\frac{1}{k}}$ in which case p is the probability that any one participant will solve the whole problem independently. This reduces the total probability under cooperation to the following:

$$P_r = [1 - (1 - p^{1/k})^r]^k$$

This relationship shows that the probability of cooperative success increases with the number of k steps and the number of ***r*** participants. Figures C.1 and C.2 show this relationship graphically.

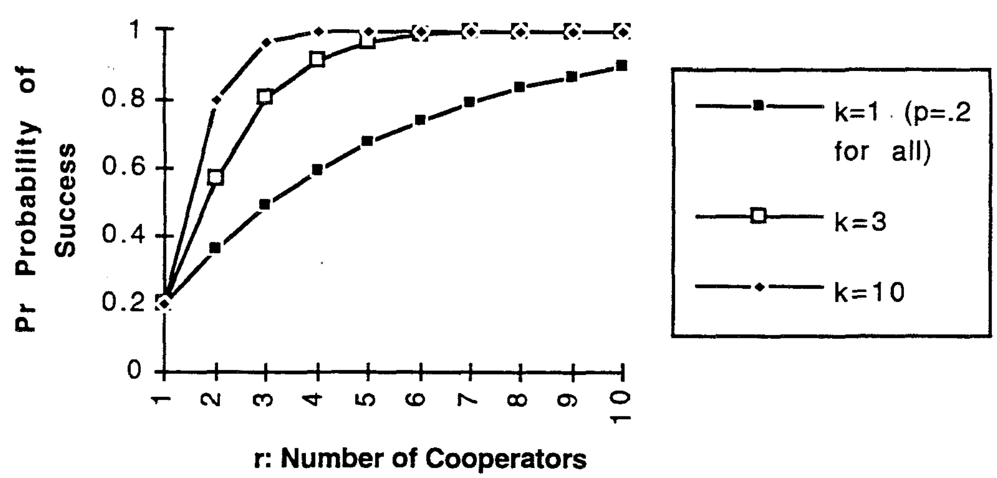

Figure C.1—Probability of Success as a function of the number of cooperators (r) and subproblems (k)

As is quite clear from these two graphs, the probability of success increases with the number of individual cooperators and the number of discrete subproblems that must be solved sequentially. The influence of the number of subproblems may be surprising. But Rittel noted that "it is evident that in group situations even poor individual abilities and small contributions can prove useful for the total solution." This was also the finding of the much more recent computer simulation of cooperating agents. (Clearwater, Huberman, & Hogg, 1991)

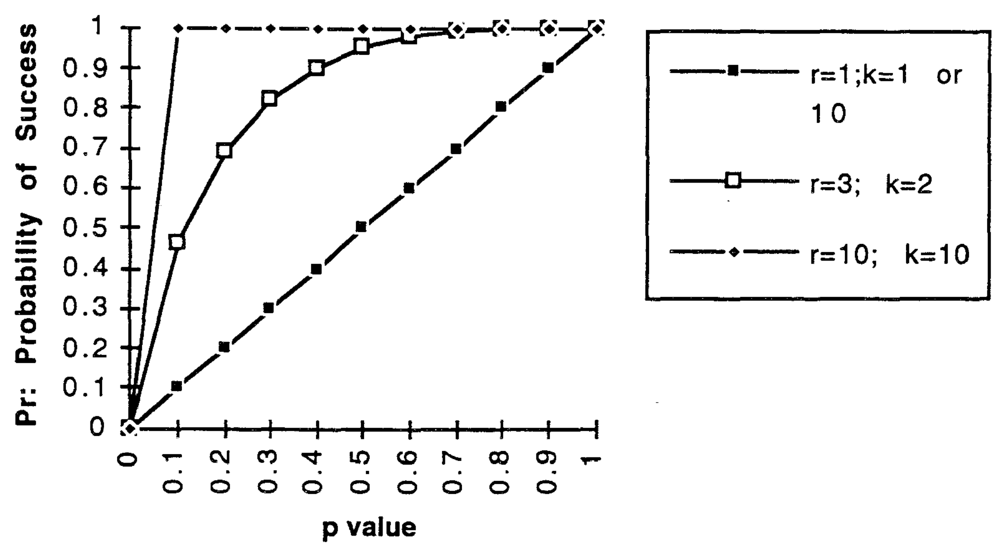

Figure C.2—Probability of Successful Problem Solving as a function of the individual probabilities (p) and the number of cooperators (r)

ALBERT LINK: COOPERATIVE RESEARCH AND THE PRODUCTION OF KNOWLEDGE

In their book, *Cooperative Research in U.S. Manufacturing,* Albert Link and Laura Bauer present a public goods model of R&D spending that illustrates how cooperation generates additional R&D, and that increased R&D is likely basic research-related activities. (Link & Bauer, 1989). The following discussion paraphrases their Chapter 6.

The model is based on the assumption that R&D is an investment that produces technical knowledge and such knowledge can be viewed as a public good that eventually diffuses through industry and society. The model also assumes that R&D is a homogenous input (see Figure C.3).

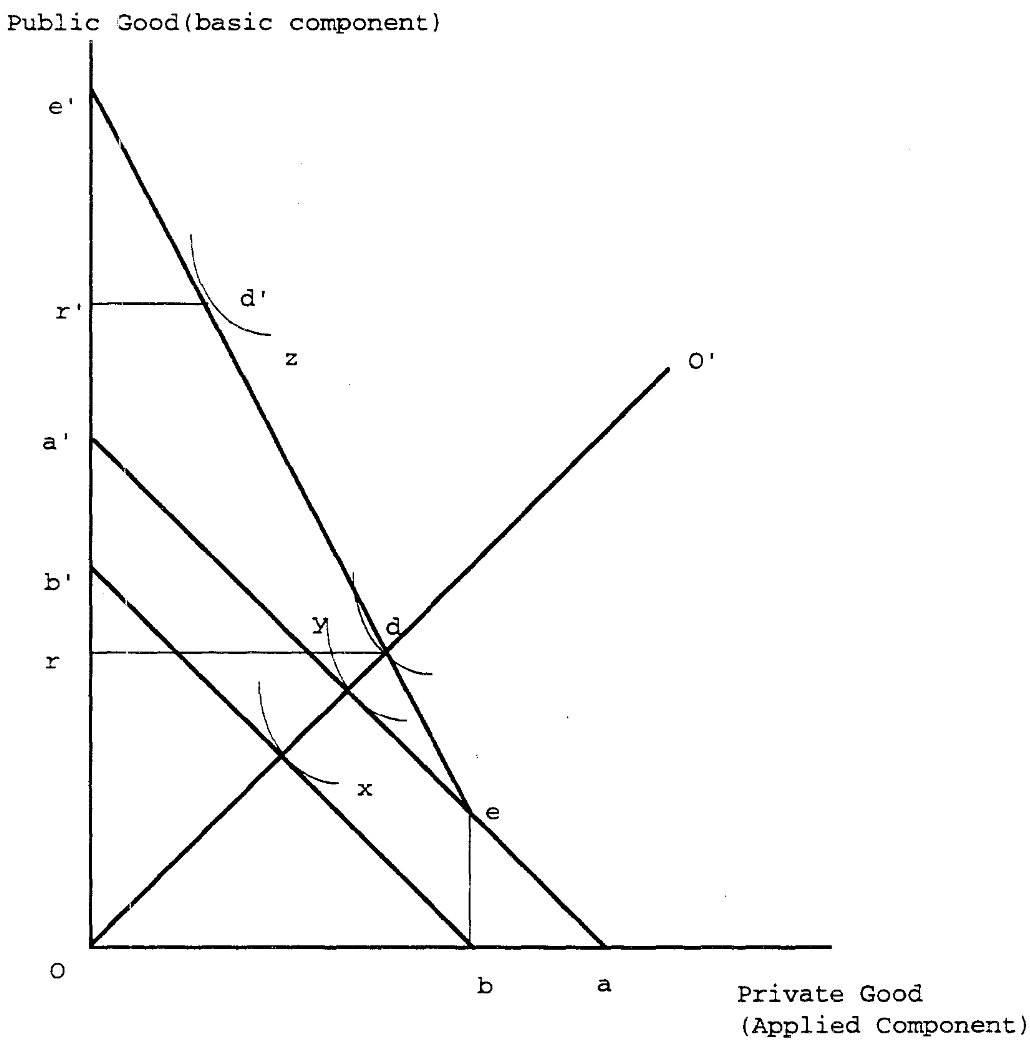

Figure C.3—Link's Public Good Model of R&D Spending

Assume that an industry is composed of two firms, A and B. Both invest independently in basic research. The knowledge generated from basic research is considered to have public good characteristics.

Each firm has an initial endowment of resources. This can be viewed as the R&D budget that can be allocated to the applied component of R&D (a private good), to basic research (a public good) or to any combination. The initial resources are shown as Oa for firm A and Ob for firm B.

The specific transformation curves between the two research components are labeled aa′ and bb′ for Firm A and Firm B, respectively. The slope of the curves (line) is the marginal cost of producing a unit of basic technical knowledge in terms of the applied component. Curves x, y, and z are the isoprofit curves. And line OO′ is the locus of optimal investment choices for the two firms acting independently.

Thus, if the firms act independently to maximize profits they will seek solutions along the OO′ line. However, since both firms must use identical amounts of the public good (by definition), both firms must simultaneously reach an identical and unique allocation on OO′.

The only possibilities for such identical allocation is along the line ee′. If both firms allocate all resources to basic research, the simultaneous solution will be at e′. If Firm B allocates all resources to the private component, the only simultaneous solution is at point e.

If the firms act independently, seeking to maximize profits, they will simultaneously reach a solution at the intersection of ee′ and OO′ at point d. At this point, each firm receives an identical amount of public good and private good.

But since the slope of ee′ is steeper than that of aa′ or bb′, the isoprofit curve at d is not tangent to ee′. Thus, the firms can be made better off by moving to the allocation at d′. This requires cooperation in R&D. Without cooperation, because of the free rider problem, the firms would have no incentive to move to this point. With cooperation, the technical knowledge will increase from Or to Or′.

In short, R&D cooperation will result in an increase in basic R&D spending. And as shown by Rittel, solutions will occur faster. And the more that cooperate, the faster and more successful such cooperative efforts will be.

Moreover, Link's model is not dependent on there being only two firms. It is easily extendable to multiple firm industries as shown in his book.

The implications of this for disrupting the fundamental technology policy dilemma are profound. Reduce anti-trust restrictions, encourage cooperation, and the appropriability justification for government subsidies of R&D diminishes substantially. Moreover, the logic of global competition and free trade implies that the collusion potential is very small. Thus, one solution to the technology policy dilemma is to reduce all barriers to cooperation and free trade. Not only will collusion problems diminish to zero, basic research may increase along with the rate of innovation. The increase in global wealth from free trade will generate the demand for the increasing quantities of innovative products.

Appendix D

GAME THEORY MODEL OF COOPERATIVE RESEARCH AMONG COMPETITORS

The following summarizes the game theory model of Sinha and Cusumano of cooperative joint venture research among competitors. Their model suggests that if firms have complementary skills and resources, then they would prefer to cooperate on research where the technology is more appropriable, such as in applied research. (Sinha & Cusumano, 1991). While the authors consider their model more sophisticated than the Link model in Appendix C, the authors make a number of very simplifying assumptions which are not consistent with the dynamic global innovation environment.

The following discusses the model and results. The derivation and proof is found in the original article.

THE MODEL

The model is based on a homogeneous goods industry with demand $Q=Q(P)$. The n firms in the industry have unequal costs and behave noncooperatively, each maximizing its profits constrained by the decisions of all other firms.

The issue of the model is how much to invest in an R&D project that requires R dollars of investment. The project will reduce the marginal cost of production by a factor of B. B, like R, is a random variable.

The game requires firms to choose whether to participate in a research joint venture (RJV) or do the R&D on their own. Once they choose, the stochastic results of the R&D become known. For simplicity, the model assumes a maximum of one RJV in the industry working on this R&D project.

The R&D project is in the nature of a patent race with one and only one winner.

If cooperating firms have complementary skills and resources then the probability of success may be higher than that for a member proceeding alone. The model does contemplate organizational difficulties reducing the probability of success below that of the firm acting alone.

Cooperating firms which succeed in the patent race are assumed to derive revenue from other firms in the industry which do not succeed.

MODEL RESULTS

The Sinha and Cusumano model implies the following propositions and corollaries. It is important to keep in mind that the assumptions of the model restrict its generalizability.

Proposition 1. Other things being equal, a firm will prefer to cooperate in research if the complementarity of skills and resources of the partners is high.

Proposition 2. Other things being equal, firms will prefer to cooperate if the cost of an R&D project is high.

Proposition 3. Other things being equal, the smaller a firm's share in total cost of the R&D project, the more likely it will be to cooperate in research.

Corollary 1. The larger the subsidy (from the government) toward the cost of the cooperative R&D project, the more likely will a firm be to cooperate.

Proposition 4. The larger a firm's share in expected royalties the more likely will it be to cooperate in the research.

Corollary 2. A firm may want to cooperate with more partners if such an increase in the number of partners will reduce its share in the cost of the R&D project more than it will reduce its share in expected royalties.

Proposition 5. If the complementarity factor of a firm is greater than unity then, other things being equal, the higher the market share of a firm the more likely will it be to cooperate in the research.

Proposition 6. Other things being equal, a firm will prefer as small a partner in an RJV as possible.

Proposition 7. Firms without complementary skills and resources will prefer to cooperate in areas where technology is less appropriable and/or the benefits are small. Firms with complementary skills and resources will prefer to cooperate in areas where the technology is appropriable and/or benefits are high.

Proposition 8. An RJV with only a few firms in the industry, each with high complementarity, increases consumer surplus.

DISCUSSION OF RESULTS

Sinha and Cusumano found that complementary skills and resources are the most important fact influencing a firm's decision to participate in an RJV. They illustrate the results with the following figure and discussion.

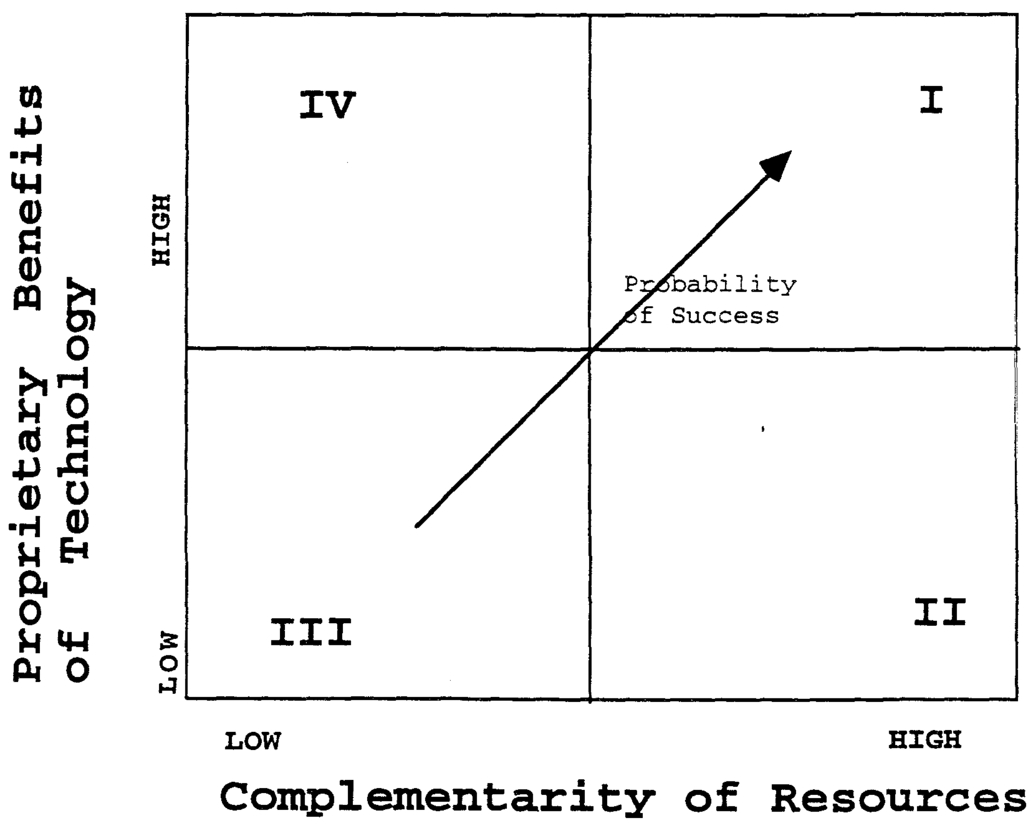

Figure D.1—Probability of Success of Four Types of Research Joint Ventures

Quadrant I. RJV's have high levels of complementary skills and resources as well as high proprietary benefits. These involve projects close to commercialization with clear and focused areas of research.

Quadrant II. Projects have high levels of complementarity but low expected proprietary benefits. For the authors, this includes focused but still basic technology or applied areas where patents would be difficult or unwise to obtain. Firms are viewed as having little reason to cooperate on such projects. Because the potential returns to society are high, there may be a case for government subsidy for such projects.

Quadrant III. Projects have low complementarity of skills and resources and low proprietary benefits. This includes basic research and applications difficult to patent. The authors assert, perhaps erroneously if the Rittel model is applicable, that an RJV in this quadrant has a probability of success that is not much higher than that of firms doing R&D alone.

Quadrant IV. Projects have large expected benefits and high appropriability of technology but low complementarity of skills and resources of partners. Firms cooperate here for financial reasons. One of the most salient reasons is to reduce risk of very expensive R&D costs.

Sinha and Cusumano pointed out three limitations with their model. First it assumes a homogeneous goods industry. Second, it applies only to industries where low cost leads to higher market share. Third, the authors assumed an R&D project with a known expected value of cost. Fourth, they assumed the purpose of the RJV was to reduce cost, not develop new features, innovations and quality products.

One of the problems of this model the authors failed to recognize is that it assumes that complementary skills and resources are necessary conditions for improving the chances of cooperative success. The Rittel models in Appendix A show that such factors may not be particularly relevant. Rather, the mere fact that two or more firms actually cooperate on a single project markedly improves the chances for success.

As can be seen, while this model has plausible and interesting results, it is far too simplified to inform policy. It ignores completely the learning dynamics of modern innovation practice and fails

to account for the substantial increase in probability for successful searching and problem solving that cooperation generates.

Appendix E

SURVEY QUESTIONNAIRE

RAND
Innovation and Alliance R&D Questionnaire

PURPOSE: The purpose of this research is to answer important questions about R&D alliances and consortia, organizational learning, innovation and financial performance, all of which have implications for the evolving technology and trade policies. This instrument is being used to collect data from firms in the world-wide aerospace, automotive, semiconductor and computer sectors. The data obtained by this project will be complemented with public source financial, alliance and patent performance data.

CONFIDENTIALITY: Please note that **all data will be held absolutely confidential** and shall be aggregated to preserve anonymity. RAND has a long history of handling sensitive data and preserving complete confidentiality.

QUESTIONS: Should you have any questions or wish clarification, please call the project hot-line at (310) 393-0411x7688 or send e-mail to walker@rand.org.

INSTRUCTIONS:

1. The questionnaire should be completed by the executive with overall direct responsibility for research and development. (VP R&D, Technology, Engineering, etc.)

2. Please answer every question, unless the data are unavailable or the question does not apply. If you choose not to answer a question for any reason, please provide answers to the remaining questions. (A marginal note of explanation would be helpful).

3. **Please answer all questions from the perspective of the largest division or entity of the company producing products in the 3674 SIC area (Semiconductors), or for the entire company if research and development for the entire firm is centralized.**

4. Answer all scaled response questions by circling the appropriate rating using the scale indicated: 0, 1, 2, 3, 4, 5, 6, or 7. Answer other questions by filling in the answer as requested. Be sure to review the definitions of the terms used.

5. If you are unsure about how to answer a question, please give the best answer you can and make a comment in the margin or call for clarification.

6. Please return the questionnaire as soon as possible by FAX or by mail in the enclosed envelope. The FAX number is 310-393-4818, Attention: Wayne Walker, Alliance Research Coordinator. Mailing address: RAND, 1700 Main Street, Santa Monica, CA 90407-2138, Attention: Wayne Walker DTP-3. If convenient, please also send a copy of your most recent annual report or put Mr. Walker on your mailing list for the next issue of your annual report.

Thank you for your time and effort in contributing to this research project.

Firm executives who complete the questionnaire will receive a summary of the aggregated data and a final report, and are invited to visit RAND for a briefing of the research progress and results.

DEFINITIONS

The following definitions are guidelines for responding to the questions.

Research and Development (R&D) consists of all scientific and engineering activities involved in developing new products and enhancing existing products. It does not include funds spent preparing bid proposals, except to the extent the expenses meet the definition in the prior sentence.

R&D alliances. R&D alliances are partnerships established to conduct research and development. R&D alliances include all forms of R&D partnerships and teaming arrangements, including governmental partnerships, university partnerships, supplier R&D partnerships, and customer R&D partnerships. Such alliances range from informal to contractual. Minority equity ownership arrangements and joint ventures established primarily for R&D purposes also fit the survey definition of an R&D alliance. Outright acquisitions of greater than 59 percent ownership of previously existing enterprises, do not count as R&D alliances. Licensing agreements of existing technology do not count.

Alliance Research: Research and development activities conducted by any form of R&D alliance, teaming arrangement, or joint R&D venture.

R&D consortia. R&D consortia are separate organizations set up by the sponsoring firms to conduct any form of innovation research and development, usually but not always, under the National Cooperative Research Act of 1984. Any arrangement that fits this definition for consortia should be counted separately from R&D alliances.

Basic Research Research conducted to discover new scientific properties, characteristics or relationships. It may or may not relate directly to ongoing development or commercial activities. of the entity Basic research can be conducted in-house, or within joint ventures, consortia or alliances.

If any questions need clarification, please call the number listed above or send an e-mail message to the Internet address above. If any question cannot be answered please so indicate and complete the balance of the instrument. Terms marked with an asterisk are defined above.

1. Company (or entity) ______________________________

2. Name, title and phone number of individual completing the survey:

Name	Title	Follow-up Phone Number

3. Number of employees in entity or company	
4. Number of scientists and engineers in research and/or development organization of entity	
5. Fiscal year end	

6. Number of R&D alliances in which the entity participates	**Circle One:** 0 1-5 6-10 11-15 1 16-20 21+
7. Number of R&D consortia in which entity participates	**Circle One:** 0 1 2 3 4 5+

8. From your perspective, what has been the mean overall level of success of entity R&D alliances*?	Failure ------------------Complete Success (0) (7)
a. with US firms	0 1 2 3 4 5 6 7 NA
b. with Japanese firms	0 1 2 3 4 5 6 7 NA
c. with European firms	0 1 2 3 4 5 6 7 NA
d. with universities	0 1 2 3 4 5 6 7 NA
e. with government entities	0 1 2 3 4 5 6 7 NA

9. What is the mean overall level of success of consortia of which firm is a member?	Failure ------------------Complete Success (0) (7) 0 1 2 3 4 5 6 7 NA

10. Assuming researchers can be categorized on a scale of 0-7 in terms of their expertise and ability to innovate, what is the mean level of researcher you would assign to the following?	Least innovative-----------Most innovative and proficient and proficient (0) (7)
a. a new R&D alliance	0 1 2 3 4 5 6 7
b. a new solely privately funded consortia	0 1 2 3 4 5 6 7

c. a new consortia with major government funding	0 1 2 3 4 5 6 7

11. Please indicate the frequency of the following types of problems with alliances and consortia:	Never--------------------Always a problem occurs (0) (7)
a. High negotiation costs and delays on start-up	0 1 2 3 4 5 6 7
b. Development of dependencies on partner(s) that later jeopardize firm competencies and abilities to respond to customer demands	0 1 2 3 4 5 6 7
c. Shirking of responsibilities by R&D partner	0 1 2 3 4 5 6 7
d. Loss of key employees to partner	0 1 2 3 4 5 6 7
e. Failure of partner to give sufficient priorities to R&D development or production requirements of your firm	0 1 2 3 4 5 6 7
f. Partner or consortia members assign too many low level researchers to the project and not enough key researchers	0 1 2 3 4 5 6 7
g. Inadvertent loss of key data, product concepts, and business plans to partners which later use the information against the firm directly or share it with firm competitors	0 1 2 3 4 5 6 7
h. Intentional acquisition of knowledge, learning and skills by partners which use the information to gain unfair competitive advantages	0 1 2 3 4 5 6 7

12. Please rate the importance of each of the following for your firm, as measured by the firm's actual planning, management and organizational design practices and implementation efforts:	No ------------------Absolutely importance critical at all (0) (7)
a. Top-down strategic planning by management	0 1 2 3 4 5 6 7
b. Communication of top-level strategy and vision to all employees	0 1 2 3 4 5 6 7
c. Faithful adherence by firm managers to top management's strategy, vision and plans	0 1 2 3 4 5 6 7
d. Implementing management strategies and vision at all levels	0 1 2 3 4 5 6 7
e. Individual business awareness by base level employees and responsibility for solving problems arising from changing market conditions, customer needs and technological demands	0 1 2 3 4 5 6 7
f. Problem solving, quality improvement and process re-engineering with cross-functional teams	0 1 2 3 4 5 6 7
g. Individual learning at all levels	0 1 2 3 4 5 6 7

h. Increasing overall organizational learning capabilities at all levels with enhanced communication technologies (e-mail, groupware, etc.) and a highly interactive and cooperative culture.	0 1 2 3 4 5 6 7

13. Assume you have been presented plans to enter into an R&D alliance. Please indicate the importance of each factor in deciding whether to recommend entering into the alliance:	No ------------------Absolutely importance critical at all (0) (7)
a. Risk sharing and overall cost reduction	0 1 2 3 4 5 6 7
b. Accelerating the return on investment	0 1 2 3 4 5 6 7
c. Sharing investments in manpower or equipment	0 1 2 3 4 5 6 7
d. Efficiency creation through economies of scale and specialization	0 1 2 3 4 5 6 7
e. Ability to commercialize new technologies faster	0 1 2 3 4 5 6 7
f. Ability to learn new technologies and processes	0 1 2 3 4 5 6 7
g. Increased connection with target markets and consumers	0 1 2 3 4 5 6 7
h. Ability to appropriate maximum short to medium term financial benefits from the alliance research	0 1 2 3 4 5 6 7
i. Ability to gain more knowledge from the partner than is revealed to the partner(s)	0 1 2 3 4 5 6 7
j. Enhancing long-term learning, including firm-wide innovation, manufacturing and marketing expertise	0 1 2 3 4 5 6 7
k. The cost of establishing the alliance	0 1 2 3 4 5 6 7
l. The cost of monitoring partner performance	0 1 2 3 4 5 6 7
m. Costs to the firm if the partner fails to perform or intentionally takes advantage of the alliance for competitive reasons	0 1 2 3 4 5 6 7
n. Opportunities for sharing in the creation and financial benefits of new technologies and markets	0 1 2 3 4 5 6 7
o. The risk that fruits of research can be lost more readily since more firms are involved in R&D efforts	0 1 2 3 4 5 6 7
p. The risk of opportunistic behavior by partner(s) and the potential for detecting, monitoring and preventing it	0 1 2 3 4 5 6 7
q. The potential for developing high levels of trust with the particular potential alliance partner	0 1 2 3 4 5 6 7

14. What is the overall quality of information communicated to you from the following in terms of frequency, timeliness, usefulness and value for the innovation activities of your firm?	No value---------------------Extremely high quality (0) (7)
a. R&D Managers at alliance firms (average of all firm R&D alliances)	0 1 2 3 4 5 6 7

b. R&D Managers at consortia firms (average of all firm consortia)	0 1 2 3 4 5 6 7
c. Vice-President of Marketing for your entity or firm	0 1 2 3 4 5 6 7
d. Vice-President of Manufacturing for your entity or firm	0 1 2 3 4 5 6 7

15. Some firms have adopted a product development process from the Japanese called Quality Function Deployment (QFD). **QFD is a teamed based and integrating approach** for encouraging communication and cooperation among all functions involved in the development process. In contrast, the **traditional U.S. R&D management method employs a series of phased reviews** where projects proceed sequentially through the development tasks. Projects are handed off from one functional specialty to another over the development cycle. Each phase is reviewed by management before the process proceeds to the next phase. **Is new product development at your firm (or entity) structured more like fully integrated QFD or more like traditional phased review management?**	Phased----------------QFD Review or integrated 0 1 2 3 4 5 6 7

16. Current distribution of firm or entity R&D alliances	**Number of alliances with US firms**	**Number with Japanese firms**	**Number with European firms**	**Number with universities**	**Number with government entities**
	a.	b.	c.	d.	e.

For all requested data below, please use data from the fiscal year(s) which ends closest to the end of the indicated calendar year(s). Feel free to use "then year" financial data for the years in question. Also, please indicate if currencies other than U.S. dollars are used for question 17 and 21. Finally, if you prefer, you may supply the year by year figures on a separate sheet.

17. R&D* Budget Average total R&D expenditures, including IR&D funds actually spent on R&D activities. (1990-1992)	**$** **($M)**

18. For the fiscal years ending closest to the end of the 1990 to 1992 calendar years, what were the average total sales and profits for the entity or firm? (NOTE: This question is being asked directly because entity level profits are an important variable and are not generally available in published financial reports. The answers will be aggregated and, as all of the data here, held absolutely confidential).	
Average Total Entity or Company Sales 1990-1992	**($M)**
Average Total Entity or Company Profits 1990-1992	**($M)**

19. Basic Research* Average percent of total R&D expenditures spent for basic research. (1990-1992)	%
20. Alliance Research* Average percent of total R&D expenditures spent for alliance research. (1990-1992)	%
21. Consortia Research* Average percent of total R&D expenditures spent for consortia research. (1990-1992)	%

(The expenditures used to compute or estimate the answer for number 19 may overlap with those in 20 and 21. Those in 20 and 21 should be mutually exclusive.)

Thank you very much for your participation in this study.

Appendix F

SURVEY COVER LETTER AND FOLLOW-UP CORRESPONDENCE

RAND

July 6, 1994

Mr. '
President

Dear Mr.

RAND is conducting extensive research on R&D alliances and firm performance in the aerospace, automotive and semiconductor sectors. This research has important implications for global and domestic business strategies. As is clearly evident from various recent government initiatives, the research may lead to important insights for the technology policies of the major industrialized nations, as well. For instance, the semiconductor industry's experience with alliances and consortia has lately been cited as an example from which others might profit.

The attached questionnaire requests data on your firm's alliance and consortia experience, along with your perceptions of the advantages and problems of such alliances. The data you provide will supplement and substantially enrich the information available from existing financial, patent and alliance databases.

The questionnaire has been designed for ***fast*** and ***easy*** completion by the executive responsible for research and development related to Aircraft Manufacturing (SIC 3721). The first 15 questions can be completed in a few minutes, while the remaining six questions may require very modest additional effort.

Please note that **all data will be held in strict confidence** and will be aggregated to preserve anonymity. As you may know, RAND has a long history of handling sensitive data and preserving complete confidentiality.

We would like to invite you to visit RAND as our guest, at your convenience and on an informal basis, to review the status of this research, should you be in the Los Angeles area over the next few months. In addition, we will provide you with a detailed written summary of the results of the research as soon as possible.

310 · 393 · 0411

1700 Main Street, PO Box 2138
Santa Monica, CA 90407-2138

RAND

July 6, 1994 Page 2

Moreover, feel free to contact our lead researcher, Wayne Walker, at 310-393-0411 ext. 7688 to discuss preliminary trends emerging from the research. He can also be reached on the Internet at walker@rand.org. Mr. Walker's doctoral dissertation in the RAND Graduate School will be partly based on the data generated by the questionnaire, and analysis of them.

Finally, please note that while the three of us are supervising this research, the research plan has also been favorably reviewed by the RAND Graduate School Advisory Board consisting of Kenneth Arrow, Marian Diamond, Gary Hufbauer, Leon Lipson, Michael May, Condoleezza Rice, Henry Rowen, Thomas Schelling, Albert Wheelon and James Wilson.

Your attention to the questionnaire will be greatly appreciated by RAND, the Critical Technologies Institute and Project Air Force. The results will be potentially important for technology policymaking thoughout the industrialized world. Moreover, they may have significant implications for your firm's technology strategies and policies.

Sincerely yours,

George L. Donohue
Director
Project Air Force

Stephen M. Drezner
Director
Critical Technologies Institute

Charles Wolf, Jr.
Dean
Rand,Graduate School

«Today's Date»

«Salut» «FirstName» «LastName»
«Title»
«Company»
«WkAddress»
«WkCity», «WkST» «WkZip»

Dear «Salut» «LastName»:

Recently, we sent you a fax reminding you of the questionnaire on R&D alliance experience that we sent your firm in April. As several have requested replacement copies of the questionnaire, we are sending the enclosed copy for your convenience.

Also attached is a generic version copy of the original cover letter that outlines the project. As we indicated in the faxed reminder, several very interesting (positive and negative) correlations are emerging from analysis of pre-existing alliance and patent data and early questionnaires returned, including the following:

- Patent performance and the number of R&D alliances
- Three-year profit performance and the number of R&D alliances
- Top down organizational strategies and profits
- Experience with alliances and perceived successes of alliances
- Strategy focus on economic concerns and the frequency of alliance problems

Response to the recent follow-up communications has been very good. We look forward to your participation so that we can include your firm in the aggregated data analysis. Moreover, we look forward to providing you with a unique analysis of patent and financial performance as a function of alliance experience and managerial attitudes toward alliance strategies.

Thank you for your participation.

Very truly yours,

Wayne G. Walker
Alliance Project Coordinator

Appendix G

COMMENTS FROM EXECUTIVES

GENERAL QUESTIONS AND OBSERVATIONS:

Why do international alliances have a uniformly positive impact on patent production?

- International alliances may cover more complementary expertise and be aimed further out. (Semiconductor executive)
- First of all, most of the companies which will take part in the international alliances can be characterized as highly competent and enthusiastic about research and development as well as the new business expansion. These companies, regardless of the domestic or international nature would be highly motivated in patent productions and profits...and would be mutually stimulated based on the different cultural background[s]. (Semiconductor executive).
- Patents are often used as defensive measure to ensure access to your own technology. When entering a partnership or alliance you will look more carefully at your position and I would expect more patents to be taken out, particularly if there are foreign partners. (Aerospace executive)
- International alliances may be expected to have a positive impact on patent production since the technological approaches pursued in different global regions can be expected to be divergent. In fact, it is also true that the problems and issues raised in different global markets are not the same, and therefore an international technology perspective on a broader range of issues should produce a broader range of solutions (patents). Finally, the existence of an international alliance may foster additional impetus to protect intellectual property globally rather than just in the U.S., leading to more foreign filing of patents. (Automotive executive)
- While comments would be speculative, there may or may not be a causal connection. However, patents are clearly opportunity driven. The more foreign markets and technological fields in which a firm has

alliances, the more patents will be generated. Firms active in alliances are more engaged in the marketplace and will have a more lively business, and therefore will be more innovative. (Aerospace executive)

- With international alliances, firms try to be more protected and this can be tied to increased patent rates. (Semiconductor executive)

- I am not sure of the causal flow from alliances to patents to profitability (that this research suggests). The direct line could be from alliance to profitability with patents just a consequence of the alliances. (Aerospace executive)

- In many cases alliances are used to leverage in-house R&D capability. Alliances ebb and flow in effectiveness. The newer the alliance, the better the results. The longer in place, the more stagnant they become. However, we have one long-standing partner which has such an insatiable appetite to rule the world that it really keeps us on our toes. (Automotive supplier firm executive).

- There may be a lot more insights as to what kinds of positive impact are caused by international alliances. But, the individual competency on research and development as well as the careful cross-fertilization of R&D efforts are the two major factors of success, which may underlie your research findings.

SEMICONDUCTOR QUESTIONS:

Why would U.S. firms be negatively influenced by domestic alliances across the board, but for all firms domestic patents have a positive impact on patents?

- Domestic semiconductor alliances are more focused on getting the job done. Would expect a neutral impact of domestic alliances rather than a negative impact. But for Japanese semiconductor companies, patent production is very important. It is one of the few ways in which Japanese engineers can stand out. Moreover, Japanese semiconductor companies develop their reputations based on patent production.

- The U.S. semiconductor firms are competitors and this may inhibit their alliance relationships.
- While companies which take part in international alliances are mutually stimulated based on different cultural backgrounds, the U.S. semiconductor firms [are] negatively influenced by domestic alliances across the board. It is likely that the U.S. semiconductor firms are not quite stimulating with each other due to the cultural similarity.

Why do E.U. only semiconductor alliances have a positive impact on patents, but negative on profits?

- Europe may be more science focused in engineering because they may be trying to find niches or leapfrog technology so they don't have to compete with U.S. or Japan companies.

AUTOMOTIVE QUESTIONS:

Why do international alliances have a negative impact on profitability for U.S. automotive firms?

- Since the U.S. automotive industry is still in the process of becoming global, the full efficiencies to be expected through international alliances are not yet comprehended. Vehicles are (or have been) designed specifically for specific markets, and the US/EU/Asian, etc. vehicles do not benefit from technology developments across borders to the extent they could or should. It is anticipated that as our business becomes globally integrated, and technology planning for the US, EU and elsewhere becomes integrated, this negative influence on profits should be reduced.... Remember that the growth in research alliances is a relatively recent phenomenon, and that the full benefits are probably yet to be achieved.
- Three reasons: (1) Alliances are being formed with firms in developing countries. There is not enough capital to yield ROI for 10 years out, because it is very expensive to transplant automotive capability without incredibly high costs. Developing countries have

very little to offer. (2) Most of the developing countries are under central planning. There are high and intense pressures to obtain licenses at little or no cost to sell products produced in the developing countries back to the U.S. This causes all kinds of problems with existing suppliers. (3) All other international alliances are with competitors who are for the most part running new, fast, clean factories at very low marginal costs. In the U.S. firms are still working with old and expensive equipment.

Why would alliances, international and domestic, have a negative impact on U.S. automaker patent productivity?

- Patent productivity for U.S. automakers is likely reduced through alliances since: (1) the total number of employees is increased by the alliance, (2) truly proprietary work is still kept 'in house,' (3) in alliances, the partner may patent more frequently than the automaker.

Why do E.U. only alliances have a negative impact on patents but a positive impact on profits? (This is the only sector where E.U. agreements have these effects. In the other two sectors it is just the reverse.)

E.U.-only alliances probably reduce patents for automakers since more technology is "purchased" from suppliers. This strategy has been employed for some time, where specific technical needs are communicated to suppliers for solution. Hence, the intellectual property becomes supplier owned, as do the patents. Significant efforts at supplier cost reduction by the automakers over the past several years in the E.U. likely have contributed to the positive impact on profitability.

AEROSPACE QUESTIONS:

Why do U.S. Aerospace companies benefit so much from international alliances?

- The aerospace sector is by its nature global. The products are easily or self-transportable and have a high value per unit weight. And the investment required for a major project is now so large that, certainly in the field of civil projects, partnerships with foreign concerns are needed to raise the investment and provide access to markets to realize profitable sales.
- The aerospace customer is usually a government. The odds are favored for profitability and sales if there is a local alliance connection.
- Teaming is the key to many international sales, and often the alliance creates, essentially, a monopoly in the international marketplace.

Why do E.U.-only alliances have a positive impact on patents, but negative on profits?

- Alliances involve an overhead and are inherently less efficient than operating by yourself. This has to be recouped by access to a bigger market. Your findings would suggest that the E.U. market is not big enough for this and the U.S. domestic market is marginally so.
- In the E.U., alliances may be an excuse to spend R&D money. E.U. companies believe in high levels of research and this generates patents, but not necessarily profits.

Appendix H

HYPOTHESIS 2.3.4. AND 5 SURVEY QUESTIONNAIRE DATA

The following is the portion of the combined questionnaire and pre-existing database data used to analyze the last four hypotheses. The sector patents, R&D budget, sales and profits variables have not been included to preclude loss of confidentiality for the responding firms.

Quest'r Number	totrdag	Success Index	problfrq Index	topdown index	learn index	mutlearn focus	oppfocus index
1	3	0.190	0.54	0.79	0.64	0.88	0.81
2	0	0.619	0.43	0.61	0.68	0.67	0.69
3	10	0.333	0.5	0.93	0.82	0.95	0.67
4	10	0.429	0.5	0.86	0.75	0.79	0.76
5	23	0.429	0.54	1	0.75	0.64	0.64
6	0	0.286	0.48	0.64	0.79	0.81	0.6
7	0	0.476	0.39	0.79	0.82	0.74	0.43
8	13	0.881	0.55	0.57	0.79	0.88	0.71
9	0	0.667	0.23	0.64	0.46	0.74	0.26
10	0	0.000	0.27	0.96	0.82	0.81	0.55
11	15	0.619	0.2	0.75	0.5	0.71	0.6
12	8	0.476	0.14	0.82	0.71	0.55	0.36
13	2	0.000	0.34	0.82	0.89	0.69	0.5
14	34	0.238	0.43	0.71	0.61	0.79	0.5
15	15	0.857	0.39	0.89	0.89	0.6	0.4
16	1	0.429	0.32	1	0.93	0.71	0.62
17	0	0.571	0.34	0.39	0.86	0.64	0.33
18	7	0.476	0.48	0.89	0.61	0.86	0.38
19	0	0.000	0.45	0.68	0.64	0.76	0.62
20	0	0.571	0.09	0.82	0.82	0.62	0.24
21	25	0.429	0.36	0.79	0.54	0.69	0.5
22	0	0.190	0.55	0.82	0.75	0.79	0.57
23	0	0.000	•	0.82	0.68	0.67	0.6
24	0	0.000	0.59	0.71	0.75	0.5	0.48
25	0	0.619	0.64	0.93	1	0.86	0.36
26	0	0.476	0.39	0.86	0.71	0.69	0.4
27	45	0.571	0.3	1	1	0.98	0.69
28	28	0.762	0.36	0.75	0.64	0.83	0.43
29	3	0.524	0.21	0.29	0.93	0.79	0.38
30	1	0.190	0.27	0.89	0.93	0.79	0.36
31	6	0.476	0.46	0.86	0.96	0.79	0.57
32	4	0.095	0.59	0.75	0.71	0.79	0.48
33	1	0.571	0.25	0.93	0.93	0.65	0.4
34	8	0.429	0.45	0.64	0.57	0.6	0.52
35	2	0.238	0.38	0.93	0.86	0.52	0.24
36	5	0.714	0.43	0.68	0.71	0.76	0.64
37	0	0.000	0.57	0.89	0.82	0.79	0.69
38	3	0.429	0.75	0.82	0.79	0.83	0.9
39	0	0.190	0.5	0.75	0.86	0.79	0.48
40	0	0.762	0.41	0.39	0.61	0.64	0.55
41	0	0.571	0.54	1	1	0.79	0.62
42	0	0.238	0.39	0.39	0.68	0.64	0.52
43	0	0.238	0.27	0.82	0.79	0.67	0.36
44	0	0.000	0	0.71	0.71	0.81	0.81
45	7	0.762	0.23	0.96	0.79	0.81	0.62
46	5	0.238	0.46	0.82	0.61	0.69	0.52
47	65	0.524	0.46	0.68	0.79	0.64	0.4
48	5	0.286	0.46	0.71	0.79	0.67	0.33
49	0	0.429	0.48	0.89	0.79	0.74	0.71
50	1	0.333	0.32	0.64	0.79	0.67	0.45

51	20	0.571	0.27	1	0.93	0.67	0.52
52	0	0.476	0.54	0.68	0.75	0.71	0.57
53	0	0.429	0.5	0.64	0.79	0.69	0.62
54	2	0.286	0.43	0.89	0.71	0.6	0.5
55	12	0.524	0.27	0.79	0.86	0.74	0.26
56	13	0.381	0.57	0.64	0.79	0.67	0.38
57	2	0.429	0.5	0.79	0.75	0.76	0.62
58	0	0.619	0.52	0.64	0.75	0.74	0.64
59	3	0.286	0.63	1	1	0.88	0.76
60	0	0.238	0.45	0.79	0.54	1	0.86
61	1	0.000	0.43	1	1	0.88	0.76
62	0	0.333	0.32	0.86	0.79	0.79	0.71
63	4	0.238	0.27	0.54	0.68	0.64	0.5
64	0	0.000	0.43	0.71	0.71	0.69	0.48
65	33	0.333	0.2	1	1	0.81	0.33
66	3	0.238	0.27	0.54	0.68	0.64	0.5
67	0	0.000	0	0.5	0.71	0.52	0.57
68	6	0.000	0.55	0.89	0.64	0.74	0.69
69	2	0.000	0.3	0.86	0.79	0.71	0.64
70	3	0.524	0.38	0.89	0.82	0.71	0.38
71	68	0.714	0.25	0.79	0.57	0.9	0.52
72	2	0.476	0.3	0.96	0.79	0.74	0.4
73	8	0.476	0.36	0.71	0.68	0.83	0.57
74	2	0.619	0.36	0.86	0.71	0.79	0.5

Quest'r Number	log sdcallrd	Economic Focus	qfd	Inflo-In	Inflo-Ex	Princip Comp. 1	Princip Comp. 2
1	1.099	0.857	1	0.286	0.429	2.509	0.100
2	0.000	0.629	6	0.643	0.714	-0.040	-0.410
3	2.079	0.714	3	0.571	0.214	1.763	1.394
4	1.099	0.914	6	0.786	0.786	2.054	-0.767
5	2.398	0.943	7	0.857	0.571	0.881	-1.891
6	0.000	0.571	2	0.571	0.714	0.141	1.002
7	0.000	0.571	6	0.714	0.714	-0.906	0.666
8	2.485	0.829	5	0.571	0.571	2.002	0.336
9	0.000	0.400	2	0.643	0.071	-2.269	1.579
10	0.000	0.771	5	0.643	•	0.761	0.227
11	2.565	0.686	4	0.571	0.643	0.060	-0.238
12	1.386	0.457	5	0.714	0.714	-2.684	-0.227
13	0.000	0.629	5	0.571	0.571	-0.673	-0.036
14	3.434	0.686	1	0.643	0.286	0.107	0.490
15	1.386	0.629	6	0.857	0.500	-1.556	-0.606
16	0.693	0.857	6	•	•	0.837	-0.976
17	0.000	0.714	4	0.571	•	-1.262	-0.576
18	1.946	0.886	6	0.857	0.643	0.835	0.330
19	0.000	0.686	2	0.714	0.643	0.412	0.120
20	0.000	0.571	2	•	•	-2.305	-0.028
21	2.944	0.800	7	0.857	0.857	0.025	-0.750
22	0.000	0.629	5	0.786	0.286	0.147	0.646
23	0.000	0.657	1	0.857	•	-0.275	-0.424
24	0.000	0.629	0	0.000	0.571	-1.790	-1.463
25	0.000	0.629	6	0.500	0.786	-0.291	1.426
26	0.000	0.571	2	0.500	0.500	-1.297	0.319
27	2.996	1.000	7	0.857	0.786	3.169	0.408
28	2.773	0.800	6	1.000	0.714	0.517	0.400
29	1.099	0.800	2	0.571	0.571	0.103	0.153
30	0.000	0.743	2	0.571	1.000	-0.208	0.415
31	1.609	0.943	6	1.000	0.857	1.428	-0.664
32	1.609	0.600	5	0.571	0.429	-0.321	0.870
33	0.000	0.886	3	0.857	1.000	-0.235	-1.296
34	0.000	0.600	4	0.929	0.786	-1.203	-0.627
35	0.693	0.629	6	0.357	0.429	-2.619	-1.030
36	1.099	0.771	5	0.714	0.714	0.839	-0.260
37	0.000	0.771	2	0.857	0.000	1.199	-0.090
38	0.000	0.857	6	0.714	0.571	2.588	-0.387
39	0.000	0.686	4	0.714	0.429	0.028	0.513
40	0.000	0.686	2	0.429	0.714	-0.518	-0.714
41	0.000	0.629	7	1.000	0.714	0.343	0.588
42	0.000	0.543	5	0.500	0.286	-1.217	-0.084
43	0.000	0.714	1	0.857	0.429	-0.981	-0.382
44	0.000	0.829	6	0.786	0.000	2.010	-0.315
45	1.792	0.829	7	0.857	0.714	1.267	-0.093
46	0.000	0.657	4	0.571	0.714	-0.478	-0.178
47	3.611	0.314	5	0.286	0.643	-2.618	1.009
48	1.792	0.400	0	0.714	0.214	-2.378	0.963
49	0.000	0.571	0	0.714	0.714	0.189	0.339
50	0.693	0.400	2	0.786	0.500	-1.909	0.823

51	2.833	0.629	5	0.786	0.714	-0.704	-0.212
52	0.000	0.714	4	0.643	0.500	0.059	-0.322
53	0.000	0.743	0	0.857	0.714	0.262	-0.652
54	0.000	0.800	3	0.857	0.571	-0.467	-1.438
55	0.693	0.514	5	0.286	0.857	-1.803	1.103
56	1.386	0.457	2	0.857	0.429	-1.950	0.666
57	0.693	0.514	5	0.429	0.429	-0.287	0.835
58	0.000	0.600	5	0.357	0.571	0.031	0.302
59	0.000	0.886	5	0.571	0.786	2.430	0.039
60	0.000	0.800	0	1.000	0.000	3.128	1.196
61	0.000	0.829	2	0.714	0.714	2.197	0.278
62	0.000	0.686	4	0.857	0.643	0.928	0.244
63	1.609	0.629	2	0.500	0.786	-0.946	-0.418
64	0.000	0.800	3	0.429	0.429	-0.053	-0.727
65	3.135	0.571	5	0.357	0.714	-0.914	1.317
66	0.693	0.629	2	0.500	0.786	-0.946	-0.418
67	0.000	0.743	4	0.571	0.429	-0.863	-1.892
68	1.099	0.829	2	0.000	0.000	1.158	-0.710
69	1.099	0.771	2	0.714	0.286	0.566	-0.642
70	0.693	0.771	5	0.714	0.286	-0.451	-0.338
71	3.932	0.857	5	0.643	0.786	1.485	0.591
72	1.099	0.743	6	1.000	0.786	-0.325	-0.014
73	2.197	0.800	3	0.786	0.857	1.065	0.237
74	0.693	0.714	3	0.643	0.643	0.223	0.370

BIBLIOGRAPHY

Alic, J. A., Branscomb, L. M., Brooks, H., Carter, A. B., & Epstein, G. L. (1992). *Beyond Spinoff: Military and Commercial Technologies in a Changing World.* Boston, Massachusetts: Harvard Business School Press.

Archibugi, D. (1992). Patenting as an Indicator of Technogical Innovation: A Review. *Science and Public Policy,* 19(6), 357-368.

Arrow, K. (1962). The Economic Implications of Learning by Doing. *Review of Economic Studies,* 29(3), pp. 155-173.

Berg, S. V., Duncan, J., & Friedman, P. (1982). *Joint Venture Strategies and Corporate Innovation.* Cambridge, Massachusetts: Oelgeschlager, Gunn & Hain, Publishers, Inc.

Brockhoff, K. (1992). R&D Cooperation Between Firms--A Perceived Transaction Cost Perspective. *Management Science,* 38(4), pp. 514-524.

Brown, H., Mowery, D. C., & Perry, W. J. (1992). *The Government Role in Civilian Technology: Building a New Alliance.* National Academy of Science, Committee on Science, Engineering, and Public Policy.

Burgers, W. P., Hill, C. W. L., & Kim, W. C. (1993). A Theory of Global Strategic Alliances. *Strategic Management Journal,* 14, pp. 419-432.

BWStaff (1993b, July 12, 1993). The Business Week Global 1000. *Business Week,* pp. 59-109.

BWStaff (1993). R&D Scoreboard: In the Labs, the fight to spend less, get more. *Business Week,* June 28, 1993, pp. 102-127.

BWStaff (1994, June 27, 1994). R&D Scoreboard: What's the Word in the Lab? Collaborate. *Business Week,* p. 78.

Ciborra, C. (1991). Alliances as learning experiments: Cooperation, competition and change in hightech industries. In L. K. Mytelka (Eds.), *Strategic Partnerships, States, Firms and International Competition* (pp. 51-77). Farleigh Dickinson University Press.

Clearwater, S. H., Huberman, B. A., & Hogg, T. (1991). Cooperative Solution of Constraint Satisfaction Problems. *Science*, 254 (22 November 1991), pp. 1181-1183.

Clinton, W. J., & Albert Gore, J. (1994). *Science in the National Interest*. Executive Office of the President, Science and Technology Policy.

Cohen, J. (1977). *Statistical Power Analysis for the Behavioral Sciences*. New York: Academic Press.

Costello, R. B., & Ernst, M. (1992). *Regaining U.S. Manufacturing Leadership* HI-4173. Hudson Institute.

Cox, C. A. (April 1992). Keys to Success in Quality Function Deployment. *APICS*, pp. 25-28.

Cronbach, L. J. (1951). Coefficient Alpha and the Internal Structure of Tests. *Psychometrika*, 16(3), pp. 297-334.

Denison, E. F. (1985). *Trends in American Economic Growth.* Washington, D.C.: The Brookings Institution.

de Pury, D. (October 1994). 'Innovate or Die' is the First Rule of International Industrial Competition. *Research and Technology Management*, pp. 9-11.

Dosi, G. (1988). Innovation as an Interactive Process: from User-Producer Interaction to the National System of Innovation. In G. Dosi, C. Freeman, R. Nelson, G. Silverberg, & L. Soete (Eds.), *Technical Change and Economic Theory* London: Pinter Publishers.

Dosi, G. (1991). Perspectives on Evolutionary Theory. *Science and Public Policy*, 18(6), pp. 353-361.

Dosi, G., Zysman, J., & Tyson, L. D. (1990). Technology, trade policy and Schumpeterian efficiencies. In J. Mothe & L. M. Ducharme (Eds.), *Science, Technology and Free Trade.* London: Pinter Publishers.

Draper, D. (1991). *Statistical Data Analysis II Class Notes.*

Duysters, G., & Hagedoorn, J. (1993). *The Cooperative Agreements and Technology Indicators (CATI) Information System.* MERIT.

Ebadi, Y. M., & Utterback, J. M. (1984). The Effects of Communication on Technological Innovation. *Management Science*, 30(5), pp. 572-585.

Eureka, W. E. (1988). QFD and You; The QFD Approach; The Power of QFD; Sizing Up the Competition; Wherein Lies the Difference?; Getting Started; Appendix: Taguchi Methods. In *The Customer Dirven Company - Managerial Perspectives on QFD.* pp. 1-124. Dearborn, Michigan: ASI Press.

Foray, D. (1991). The Secrets of Industry are in the Air: Industrial Cooperation and the Organizational Dynamics of the Innovative Firm. *Research Policy*, 20, pp. 393-405.

Garvin, D. A. (July-August 1993). Building a Learning Organization. *Harvard Business Review*, pp. 78-91.

Golden, J. R. (Summer 1993). Economics and National Strategy: Convergence, Global Networks, and Cooperative Competition. *The Washington Quarterly*, pp. 91-113.

Granovetter, M. (1985). Economic Action and Social Structure: The Problem of Embeddedness. *American Journal of Sociology*, 91, pp. 481-510.

Griffin, A., & Hauser, J. R. (1992). Patterns of Communication among Marketing, Engineering and Manufacturing-A Comparison Between Two New Product Teams. *Management Science*, 38(3), pp. 360-373.

Griliches, Z. (Ed.) (1984). *R&D, Patents and Productivity.* Chicago: The University of Chicago Press.

Grossman, G. M., & Helpman, E. (1994). Endogenous Innovation in the Theory of Growth. *Journal of Economic Perspectives*, 8(1), pp. 23-44.

Hagedoorn, J., & Schakenraad, J. (1994). The Effect of Strategic Technology Alliances on Company Performance. *Strategic Management Journal*, 15, pp. 291-309.

Hagedoorn, J., & Schakenraad, J. (1991). The Internationalization of the Economy, Global Strategies and Strategic Technology Alliances. *Nouvelles de la Science et des Technologies*, 9(2), pp. 29-41.

Hagedoorn, J., & Schakenraad, J. (1992). Leading Companies and Networks of Strategic Alliances in Information Technologies. *Research Policy*, 21, pp. 163-210.

Haklisch, C. (1986) *Technical Alliances in the Semiconductor Industry.* New York University.

Hall, M. (November 14, 1994). PPC Allies Unite on Platform. *MacWeek*, p. 1.

Harbison, J. R., & Pekar Jr., P. (1993). *A Practical Guide to Alliances: Leapfrogging the Learning Curve*. Booz Allen & Hamilton.

Howells, J. (1990). The Globilisation of Research and Development: a New Era of Change? *Science and Public Policy*, 17(4), pp. 273-285.

Inman, B. R., Augustine, N. R., Branscomb, L. M., & Perry, W. J. (1991). *Technology and Economic Performance: Organizing the Executive Branch for a Stronger National Technology Base*. Carnegie Commission.

Jacobs, S. (Ed.) (1992). *High Technology Market Place Directory - 1992*. Middlebush, N.J.: Princeton Hightech Group, Inc.

Jarillo, J. C., & Stevenson, H. H. (1991). Cooperative Strategies--The Payoffs and the Pitfalls. *Long Range Planning*, 24(1), pp. 64-70.

Jenks, A. (October 13, 1994). Antitrust Watchdogs Target High-Tech Business. *Washington Technology*, pp. 1, 8 and 9.

Jenks, A. (Winter 1995). Killing Them Softly: Justice Department Targets Private R&D Partnerships. *Technology Transfer Business*, p. 68.

Johnson, R. A., & Wichern, D. W. (1988). *Applied Multivariate Statistical Analysis*. Englewood Cliffs, N.J.: Prentice Hall.

Kaulkin, D. B. (Ed.) (1993). *World Aviation Directory*. Washington, D.C.: McGraw-Hill Aviation Week Group.

Langlois, R. N., & Robertson, P. L. (1992). Networks and Innovation in a Modular System: Lessons from the Microcomputer and Stereo Component Industries. *Research Policy*, 21, pp. 297-313.

Lerner, J. (1994). The Importance of Patent Scope: An Empirical Analysis. *RAND Journal of Economics*, 25(2), pp. 319-333.

Levine, J. B. (December 21, 1992). Can Europe Survive the Chip Wars? *Business Week*, pp. 56-57.

Lewin, R. (1992). *Complexity: Life at the Edge of Chaos*. New York: Macmillan Publishing Company.

Lewis, W. (October 22, 1993). The Secret to Competitiveness. *Wall Street Journal*. p. A__.

Lind, M. R., & Zmud, R. W. (1991). The Influence of Convergence in Understanding Between Technology Providers and Users on Information Technology Innovateiveness. *Organization Science*, 2(2), pp. 195-217.

Link, A. N., & Bauer, L. L. (1989). *Cooperative Research in US Manufacturing*. Lexington, Massachusetts: Lexington Books.

Lundvall, B. A. (1988). Innovation as an Interactive Process: From User-Producer Interaction to the National System of Annovation. In G. Dosi, C. Freeman, R. Nelson, G. Silverberg, & L. Soete (Eds.), *Technical Change and Economic Theory* London: Pinter Publishers.

Maddala, G. S. (1988). *Introduction to Econometrics*. New York: MacMillan Publishing Company.

Matsuo, F. (December 6, 1994). Trade with a Moral Compass. *Wall Street Journal*, p. A20.

Merrifield, D. B. (1992). Global Strategic Alliances Among Firms. *International Journal of Technology Management*, 7(1/2/3), pp. 77-83.

Meyers, P. W. (April 1990). Non-Linear Learning in Large Technological Firms: Period Four Implies Chaos. *Research Policy*, p. 97.

Miller, R. (1994). Global R&D Networks and Large-Scale Innovations: The Case of the Automobile Industry. *Research Policy*, 23, pp. 27-46.

Mody, A. (1993). Learning Through Alliances. *Journal of Economic Behavior and Organization*, 20, pp. 151-170.

Mogee, M. E. (July-August 1991). Using Patent Data for Technology Analysis and Planning. *Research and Technology Management*, pp. 43-49.

Moran, T. H. (1993). *American Economic Policy and National Security*. New York: Council on Foreign Relations.

Mowery, D. C. (1992). The U.S. National Innovation System: Origins and Prospects for Change. *Research Policy*, 21, pp. 125-144.

Mytelka, L. K. (1990). New Modes of International Competition: The Case of Strategic Partnering in R&D. *Science and Public Policy*, 17(5), pp. 296-302.

Narin, F., Albert, M. B., & Smith, V. M. (1992). Technology Indicators in Strategic Planning. *Science and Public Policy*, 19(6), pp. 369-381.

Nelson, R. R. (1983). Government Support of Technical Progress: Lessons from History. *Journal of Policy Analysis and Management*, 2(4), pp. 499-514.

Nelson, R. R. (1959). The Simple Economics of Basic Scientific Research. *Journal of Political Economy*, 67, pp. 297-306.

Niosi, J., & Bellon, B. (1994). The Global Interdependence of National Innovation Systems. *Technology in Society*, 16(2), pp. 173-197.

Norris, K., & Vaizey, J. (1973). *The Economics of Research and Technology*. London: Alden & Mowbray Ltd.

Nunnally, J. C. (1978). *Psychometric Theory*. New York: McGraw-Hill.

Pearce, R. D. (1989). *The Internationalisation of Research and Development by Multinational Enterprises*. New York: St. Martin's Press.

Pekar Jr., P., & Allio, R. (1994). Making Alliances Work--Guidelines for Success. *Long Range Planning*, 27(4), pp. 54-65.

Peter Pekar, J. (October 28, 1994). Phone Conversation.

Peters, T. (1994). Whence Comes Innovation. *Forbes ASAP*, p. 132.

Rittel, H. (1965). Hierarchy or Team? Considerations on the Organization of R&D Cooperatives. In R. A. Tybout (Eds.), *Economics of Research and Development*. Ohio State University Press.

Rosenberg, N. (1972). *Technology and American Economic Growth*. New York: Harper and Row.

Rothwell, R. (1972). *Factors for Success in Industrial Innovations: Project SAPPHO- A comparative study of Success and Failure in Industrial Innovation*. S.P.R.U.

Rothwell, R. (1992). Successful Industrial Innovation: Critical factors for the 1990s. *R&D Management*, 22(3), pp. 221-239.

Rycroft, R. W., & Kash, D. E. (1994). Technology Policy in a Complex World. *Technology in Society*, 16(3), pp. 243-267.

Sahal, D. (1985). Technological Guideposts and Innovation Avenues. *Research Policy*, 14, pp. 61-82.

SAS Institute Staff (1994). *JMP Statistics and Graphics Guide*. Cary, N.C.: SAS Institute, Inc.

Schein, E. H. (Winter 1993). How Can Organizations Learn Faster? The Challenge of Entering the Green Room. *Sloan Management Review*, pp. 85-92.

Schmitt, R. W., & Bement, A. L. (1992). *The Competitive Strength of U.S. Industrial Science and Technology: Strategic Issues.* National Science Board, Committee on Industrial Support for R&D.

Senge, P. M. (1990). *The Fifth Discipline: The Art & Practice of the Learning Organization.* . New York: Doubleday.

Shan, W., Walker, G., & Kogut, B. (1994). Interfirm Cooperation and Startup Innovation in the Biotechnology Industry. *Strategic Management Journal,* 15, pp. 387-394.

Sinha, D. K., & Cusumano, M. A. (1991). Complementary Resources and Cooperative Research: A Model of Joint Ventures Among Competitors. *Management Science,* 37(9), pp. 1091-1106.

Skolnikoff, E. B. (1993). New International Trends Affecting Science and Technology. *Science and Public Policy,* 20(2), pp. 115-125.

Staff (1992). *Perspectives on U.S. Technology and Trade Policy: The CSPP Agenda for the 103rd Congress.* Computer Systems Policy Project.

Tent, M. (1990). International Co-operation in R&D: the Experiences of the European Community. *Science and Public Policy,* 17(5), pp. 293-295.

Tong, X., & Frame, J. D. (1994). Measuring National Technological Performance with Patent Claims Data. *Research Policy,* 23, pp. 133-141.

Torgerson, W. S. (1958). *Theory and Methods of Scaling.* New York: John Wiley & Sons.

Trajtenberg, M. (1990). A Penny for Your Quotes: Patent Citations and the Value of Citations. *RAND Journal of Economics,* 21(1), pp. 172-187.

von Hippel, E. (1988). *The Sources of Innovation.* New York: Oxford University Press.

Walker, W. G. (1994). *Resonant Organizational Learning: Enhancing Individual and Organizational learning and Their Complex Connection.* Working Paper. Unrestricted Draft No. DRU-695-RGS RAND.

Weisberg, S. (1985). *Applied Linear Regression.* New York: John Wiley & Sons.

Westney, D. E. (1988). Domestic and Foreign Learning Curves in Managing International Cooperative Strategies. In F. Contractor & P.

Lorange (Eds.), *Cooperative Strategies in International Business* Lexington: Lexington Books.

Williamson, O. E. (1975). *Markets and Hierarchies: Analysis and Antitrust Implications*. New York: Free Press.

Young, J., Gray, P. E., & Inman, B. R. (1988). *Picking Up the Pace: The Commercial Challenge to American Innovation*. Council on Competitiveness.

Zysman, J. (1992). Trade, Technology and National Competition. *International Journal of Technology Management*, 7(1/2/3), pp. 161-189.

RGSD-118